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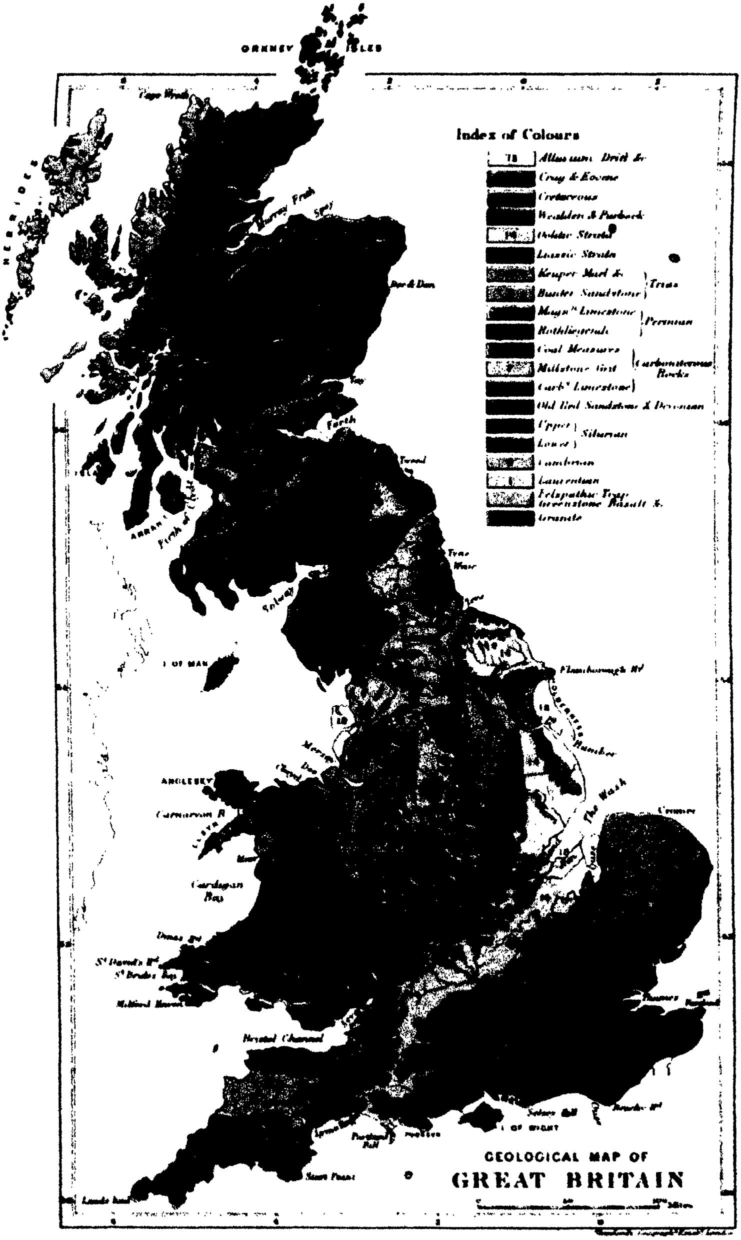
ORKNEY ISLES
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HEBRIDES
Moray Frith
Spey
Dee & Don
Tay
Forth
Tweed
ARRAN
Firth of Clyde
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Laurentian
Felspathic Trap
Greenstone Basalt &c
Granite
GEOLOGICAL MAP OF
GREAT BRITAIN
Miles

GEOLOGY

IN SYSTEMATIC

NOTES and TABLES

FOR THE USE OF

TEACHERS AND OF TAUGHT,

BY

WINTOUR F. GWINNELL, F.G.S., F.R.Met.Soc.,

Passed First B.Sc., Lond. Univ.; Queen's Gold Medallist in Zoology.
First in First-Class Honours in Geology, Botany, Physiography.
Queen's Medallist in Geology, 1865 and 1885.
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AUTHOR OF

"Notes on Botany;" also, "Notes on Mechanics, Chemistry, Geography and Mapping;" "On the Advantages of the Study of Natural Science;" "Sketch of the Geology of the Forest of Dean and District, and Report of the Long Excursion there," Proc. Geol. Assoc., 1888. "The Nautilus and its Fossil Allies;" "The Rhætic Deposits of Britain;" "Dragons, Ancient and Modern;" &c.

WITH EIGHTY ILLUSTRATIONS AND A

GEOLOGICAL MAP OF GREAT BRITAIN.

SECOND EDITION.

London:
ALLMAN & SON, LTD., 67, NEW OXFORD STREET, W.C.;
SIMPKIN, MARSHALL & CO.;
OF THE AUTHOR, WHITE HILL, GRAVESEND.

There rolls the deep where grew the tree.
  O earth, what changes hast thou seen!
  There where the long street roars, hath been
The stillness of the central sea.

The hills are shadows, and they flow
  From form to form, and nothing stands;
  They melt like mists, the solid lands,
Like clouds they shape themselves and go.—TENNYSON.

There are no natural objects out of which more can be learned than out of stones. They seem to have been created especially to reward the patient observer. Nearly all other objects in nature can be seen to some extent without patience, and are pleasant in being half seen: but the stone under his foot has for carelessness nothing in it but stumbling, no pleasure is languidly to be had out of it, nor food, nor good of any kind; nothing but symbolism of the hard heart and the unfatherly gift. And yet do but give it some reverence and watchfulness, and there is bread of thought in it more than in any other lowly feature of all the landscape.—RUSKIN'S "*Modern*

The progress of all real Science is towards compression and condensation, and its whole aim to supersede the endless detail of individual cases by the announcement of easily remembered and readily applicable laws.—SIR J. HERSCHELL.

LONDON:
Printed by G. HARMSWORTH & Co., Hart Street, Covent Garden.

1889.

TO THE SONS AND DAUGHTERS OF

LORD ARTHUR RUSSELL,

MY DILIGENT AND INTERESTED PUPILS IN THE NATURAL

SCIENCES FOR THE LAST TEN YEARS,

I Dedicate

THIS LITTLE BOOK.

PREFACE.

The First Edition of these "Notes" was issued (in lithograph) some eight years since for use by the Author's pupils. The appreciation in which they were held by these, and by teachers who introduced them into their classes, as well as the favour with which the Author's "NOTES ON BOTANY" and similar notes on other subjects were received, determined him to enlarge and publish them. The first sheet was in type three years ago, but the completion of the work has been delayed by a variety of causes, not the least being the amount of time necessary for the examination of many recent publications relating to the subject, with the object of admitting new discoveries, investigating doubtful ones, and eliminating exploded errors. This delay will account for some slight differences, chiefly of nomenclature, between the earlier and later pages, and for the addition of certain notes apparently "out of place."

The order followed is unusual; but this may be varied to suit any book or lecture course by the use of the Table of Contents.

The Author's aim has been to make the work, not a text book, nor yet a mere glossary, but a student's companion to the larger manuals and to the lecture, presenting the facts and technical terms of the subject under a compact and methodical arrangement, so as to aid the mind in grasping them and the memory in retaining them. As an epitome, too, the work will be found of value, it is hoped, to the Teacher as well as to the Taught.

In preparing it the Author has kept constantly in mind the requirements of the public examinations, and in particular those for admission to Sandhurst, Woolwich, and the Indian Forest Service; those of the Science and Art Department (Syllabus appended), and the Royal School of Mines; the University Local and B.Sc. examinations.

The map of Great Britain (in twenty colours), though adding materially to the cost, will be doubtless greatly appreciated. The illustrations (over eighty drawn by the Author and placed together in an appendix, are rough, but include, with some of great importance, several of special interest not easily accessible. The maps and sections should be coloured and copied frequently. Should another edition be called for it is intended to increase largely this part of the work. Blank pages are appended for the addition of manuscript notes and sketches, or for the attachment of printed cuttings.

The Author desires to express his great indebtedness to the personal teaching of Professor Sir A. C. Ramsay, Professor Sir W. W. Smyth, and Professor J. W. Judd at the Royal School of Mines, and to the laboratory work done under the latter. His best thanks are due, and are here most gratefully expressed, to friends who have given valuable aid in suggestions of various kinds and in reading the proof sheets; to Mr. P. E. Swinstead, B.A., Mr. P. L. Smith, Mr. Henry Walker, F.G.S., Mr. W. H. Dalton, F.G.S., late of H.M. Geological Survey, and especially to Mr. John Hogg, B.A., Mr. Grenville Cole, F.G.S., Demonstrator in Geology, Royal School of Mines, and Mr. E. T. Newton, F.G.S., F.Z.S., Palæontologist to H.M. Geological Survey.

A list of the chief works consulted is given below, and may serve as some guide to the student in his reading. Quotations are usually acknowledged.

W. F. G.

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Christmas, 1888.

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MURCHISON, SIR R. J.—"Siluria"

NICHOLSON, H. A.—"Palæontology."

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Official Syllabus in Geology for the Science and Art Department Examinations, Elementary and Advanced Stages.

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INTRODUCTION.

Geology has for its final aim to trace the progress of our planet, from the very beginning of its separate existence, through all the stages of its development down to its present condition, and is thus, if one may so speak, "the history of the prehistoric ages." It seeks to describe how each continent and island has been built up, each sea and lake hollowed out, each useful product accumulated. It restores in imagination the geographical and physiographical features of each successive age, clothing once again the bye-gone lands with their vegetation, and peopling the seas, lakes, and lands with beings as they lived in each succeeding Period—beings often admirable in their adaptation, beautiful in their simplicity, surprising in their strangeness, or terrible in their size or ferocity. Such resurrection of the past forms the chief charm of the study.

As a science it is of enormous practical value (see pp. 17-18), whilst as a study it is not only most fascinating, but when carried on in the field it ranks high as a means of intellectual training in habits of observation and in reasoning from observed data; and it has the further great advantage of being a healthy open-air pursuit, affording a delightful relief from the ordinary routine of work-a-day life; it moreover adds greatly to the pleasures of travel.

To the Englishman it offers special attractions, for his native isle is well called "the Paradise of Geologists." In no other region of equal area are so many formations represented and exposed at the surface, in none are there such ready means of access to all parts, and in few are exposures of the strata so common in escarpments, cuttings, quarries and cliffs. If there can be any royal road to geology it is that which conducts the learner to "the scarped cliff and quarried stone," the cutting and the mine, the river gorge and the mountain height. There he may con the rocky pages spread out beneath and around him, and find "sermons in stones" and "books in the running brooks." But to one ignorant of their language these have no story to relate. To facilitate the student in mastering that tongue by presenting him with the leading facts and generally accepted theories *in a methodical form, easy of cognition and convenient of reference, is the object of this little book.*

The succeeding "Notes" on the history of the science, the estimates of geological time, climatic changes and their causes, are intended for the perusal of more advanced students, referring as they do to somewhat difficult or debateable topics

Just a century ago Hutton published at Edinburgh his "Theory of the Earth," in which he maintained that the stratified rocks owed their origin to the action of water, and the unstratified and intrusive rocks theirs to the action of heat—a happy compromise between the contentions of the Neptunists and the Vulcanists, the rival geological schools of the time, who ascribed all rocks to one or other of these agencies alone. More than this, he showed that the wild dreamy speculations of the school of Catastrophists, with their convulsions, cataclysms, inundations, collisions (with comets' tails), and other occurrences equally fanciful, were totally uncalled for in explaining the origin of the rocks of the earth's crust. He insisted that in geological speculation "no powers are to be employed that are not natural to the globe, no actions to be admitted of except those of which we know the principle, and no extraordinary events to be alleged in order to explain a common appearance" In a word he held that the present is the key to unlock the past. Lyell some fifty years later revived his teaching with great success, and became the gre leader of the school of Uniformitarians which insists on the uniform action of Nature in the past as in the present; "amid all the revolutions of the globe," says Playfair, "the economy of Nature has been 'uniform.'" More recently this view has been modified by Darwin, Huxley, and Spencer, representing the school of Evolutionists, which holds that Nature not only modifies the energy and rapidity of action in her forces, but may and does from time to time bring new agencies into play—*e.g.*, man, the great disturber of nature.

Two contemporaries of Hutton—Wm. Smith, the "Father of English Geology," and Werner, the founder of the Neptunists in Germany—laid the foundations of Historical Geology by establishing the principle of an invariable Order of Superposition of Strata; and Smith further discovered that the various strata and groups of strata (Formations and Systems) were each capable of being recognized by means of their fossil contents, a discovery without which the principle of invariable superposition could have been of little practical value in the case of strata lying in localities widely apart. To explain the Succession of Life in Time thus ascertained to exist, it was at first assumed that each species of plant and animal originated by a special act of creative power exercised spasmodically, a view now generally displaced by Darwin's Theory of Evolution that "species undergo modification, and the existing forms of life are the descendants by true generation of pre-existing forms." (*Origin of Species*, *The view is now generally accepted that the main outlines of the existing continents have been almost unchanged from the earliest time known to us,* though the details of their coast lines have varied much and often, as these continental areas have, at various epochs, been successively elevated above and depressed below the surface of the sea,—local denudation and deposition greatly influencing the total result. Such oscillations, known to be still in progress (see p. 50), would be most frequent in the marginal portions, *e.g.*, the British area, and would result in the occasional production there of continental islands, island-encircled and inland seas, &c.

During the long series of geological ages the climate, not only of England, but of each hemisphere, if not of the earth as a whole, has often changed, cold and hot periods alternating. In the Pleistocene Period glacial conditions undoubtedly prevailed widely in the northern hemisphere; the supposed results of similar conditions occur in parts of the Cambrian, Devonian and Permian Systems; while semi-tropical conditions are believed to have characterised the Silurian, Carboniferous, Jurassic and Eocene Periods in Britain, all remarkable for the great abundance and variety of their life.

Four chief causes have been assigned to account for such cycles of climate, and as these are all independent, and may all co-exist, they may severally co-operate with or counteract one another.

(1) Changes in geography, *i.e.*, in the form, extent, and distribution of the land, *e.g.*, an accumulation of land in polar and of ocean in tropical regions tends to increased evaporation in the latter, and increased precipitation, largely as snow, in the former. Changes in the direction and magnitude of the ocean currents would accompany such alterations in geographical features, and produce local changes in climate, *e.g.*, the Gulf Stream, which carries northwards as much heat as is received from the sun by three million square miles at the equator, and makes Britain 12° warmer than is due to its latitude, might thus be diverted altogether from our shores.

(2) Changes in the position of the earth's axis, and hence in that of its poles, equator, and tropics. If such changes—denied by such astronomers as Newton, Laplace, Haughton, and Airy—really do occur, they must be very slight if due to the elevation of continents and mountain chains, or to the sinking of areas, however large.

(3) Changes in the seasons due to the precession of the equinoxes. The points (*nodes*) of the apparent passage of the sun across the equator occupy in successive years a slightly different position on the ecliptic, retrograding by 50 seconds of arc every year, so that a whole revolution of the nodes occurs in 25,866 years. This motion, combined with a slighter cause, brings about a complete cycle of changes of climate once in every 21,000 years; *e.g.*, our northern summer now occurs when the earth is nearly in aphelion or its furthest position from the sun; in 10,500 years it will occur in perihelion or its nearest position to the sun, the distances being respectively 93 and 90 million miles.

(4) Changes in the form of the earth's orbit, viz., a periodical variation in the eccentricity of the orbit or path round the sun, and in consequence a greater or less difference in the perihelion and aphelion distances of the earth from the sun.

At present this difference is three millions of miles, but during the last million years it has varied from one to thirteen millions, being great at periods 100,000, 200,000, 850,000 years ago. The hemisphere whose winter *occurred in aphelion had, at these times, an excess of winter over summer of 23, 28, 36 days respectively (instead of eight days less winter than summer as with us now), and with mean temperatures, in the latitude of London, for the hottest month of 105°, 113°, 126° Fahr., and for the coldest month of 5°, 6°, −7°* respectively, *that of London being at present 64° in July and 38° in January.* The shorter though hotter summer could not undo the effect of the longer and severer winter, the mass of ice and snow would thus go on accumulating from year to year, and glacial conditions would prevail until gradually, through the precession of the equinoxes, winter should come to occur in perihelion as it now does in our hemisphere, instead of in aphelion as now in the southern hemisphere, which is in consequence undergoing a modified glacial episode. A large area of the planet Mars is thought to be now under glacial conditions.

The proofs that glacial conditions prevailed in northern latitudes, even as far south as Sicily and Syria, subsequent to the period of the Tertiary deposits are threefold.—

(1) The wide-spread occurrence of *moraines* and *erratics*—boulders of rocks, ice-borne from often distant localities—resting indiscriminately on Pliocene and older strata, of *furrows* and *striæ* on hard-rock surfaces, and of rounded bosses or *roches* ;

(2) The prevalence of arctic marine shells in the Newer Pliocene and Pleistocene deposits of temperate latitudes.

(3) The present distribution of life in isolated mountainous regions, the plants and animals of these being the relics of an arctic flora and fauna which must have occupied the plains of central and southern Europe, but ascended the hills and retreated to the north as the temperature increased, and the plains became too warm. The Alpine flora, *Saxifrages*, &c., now found at heights of from 3,000 to 6,000 feet on the Alps, occurs at less elevations on the Urals and Altai, and covers the low plains of Northern Europe and Asia from 60° to 70° N. lat.

ADDITIONS AND ERRATA.

p. 13, line 23, add—see p. 47, line 35.

p. 14, The Caution is perhaps too emphatic; in line 6, read *are probably of*.

p. 16, line 22, after *latter* add *in Britain*; or for *Cretaceous* read *Jurassic*.

p. 26, line 17, for *Oliogoclase* read *Oligoclase*, line 27, for *Lencite* read *Leucite*.

p. 47, line 35, for *known to be* read *believed to be chiefly*.

p. 78, line 35, read 100 sp. of *Globigerina*; also *Rotalia*, &c.

p. iii., middle, for *Outlier* read *Dip Slope*.

p. xi., after Europe add *in Pleistocene times*.

TABLE OF STRATIFIED ROCKS.

		SYSTEMS.	FORMATIONS.		FOSSILS.	
CAINOZOIC.	Quaternary.	**15. RECENT**	Peat, Alluvium, Loess Valley Gravels, Brick-earths		"The Age of Man" and of Domestic Animals	Era of Birds, Mammals, and Dicotyledons.
		14. PLEISTOCENE	Cave Deposits, Raised Beaches Boulder Clay and Gravels		Irish Elk, Reindeer; Mammoth and Musk Ox	
	Tertiary.	**13 PLIOCENE**	Forest Bed of Cromer Norwich and Red Crags Coralline or White Crag		With Elephants, Deer, &c. With *Mastodon*; *Fusus* With Polyzoans (*Eschara*)	
		12. MIOCENE	Œningen Beds, &c.		With *Dinotherium*	
		11. OLIGOCENE	Fluvio-Marine Series		With Freshwater Shells	
		10. EOCENE	Bagshot and Barton Beds London Clay Lower London Tertiaries		*Nummulites*; *Nautilus*; *Palæotherium*; *Voluta*; *Cyrena* Sharks, Palms, &c.	
SECONDARY or MESOZOIC		**9. CRETACEOUS**	Mæstricht Beds Chalk Upper Greensand Gault		"The Age of Hippurites, Iguanodon & Mosasaurus". *Inoceramus*; *Micraster* *Ammonites*; *Hamites*; *Scaphites*	Era of Cycads, Saurians and Marsupials.
		NEOCOMIAN	Lower Greensand			
			Weald Clay Hastings Beds	WEALDEN	Fresh-water Shells, *Unio*, &c. Land Plants and Reptiles	
		OOLITIC	Purbeck Beds Portland Beds Kimeridge Clay	Upper	"The Age of Cycads, Ammonites and Reptiles" Advent of Birds (?) and of Pterodactyls (dragon-like)	
			Corallian Beds Oxford Clay	Middle	N.B. *Trigonia*; *Lima*; *Pecten*; *Rhynchonella*, *Terebratula*	
		8. JURASSIC	Great Oolite Series Inferior Oolite	Lower		
		LIASSIC	Upper Lias Marlstone Lower Lias	Lias	*Ammonites*; *Belemnites*, *Ichthyosaurus*, *Plesiosaurus*, *Gryphæa incurva*; *Lima gigantea*	
		7. TRIASSIC	Rhaetic (passage) Beds Keuper Muschelkalk Bunter		*Avicula contorta* Advent of Mammals, of Ammonites (*Ceratites* &c.), and huge Saurians	
PRIMARY or PALÆOZOIC		**6. DYAS or PERMIAN**	Dolomitic Series (Zechstein) Marl Slate (Kupfer Schiefer) Red Sandstone and Conglomerate (Rothliegende)		Advent of Reptiles "The Age of Labyrinthodonts."	Era of Brachiopods, Orthoceratites, and Trilobites.
		5. CARBONIFEROUS	Coal Measures and Millstone Grit Carb. Limestone Series		"The Age of Cryptogamic Plants, Corals and Crinoids" *Lithostrotion*, *Productus*	
		4. DEVONIAN	Upper Middle Lower	OLD RED SANDSTONE.	"The Age of Ganoid Fishes and Eurypterids" *Cephalaspis*, *Pterygotus*	
		3. SILURIAN	Ludlow Beds Wenlock Beds Llandovery (May Hill) Beds		The Advent of Fishes The Trilobites *Phacops* and *Calymene*. *Pentamerus*	
		2. ORDOVICIAN	Bala and Caradoc Beds Llandeilo Beds Arenig and Skiddaw Group		"The Age of Graptolites, Trilobites and Cystideans" *Asaphus*; *Ogygia Buchii*	
		1. CAMBRIAN	Tremadoc Slates Lingula Beds	Upper	*Angelina*; *Niobe*; *Lingula*; *Orthis*; *Olenus*	
			Menevian Beds Longmynd Group	Lower	*Paradoxides*, *Theca*; *Olenellus*; *Arenicolites*, *Oldhamia*	
Azoic or Eozoic.		**ARCHÆAN**	Pebidian on Dimetian Huronian on Laurentian		The Advent of Life (?) *Eozoon canadense*	

The limits of the above Systems are based on palæontological breaks or great changes in the fossil contents, but in the following cases this is accompanied by a stratigraphical break or decided unconformity of the strata, more or less wide-spread over Western Europe:—At base of system 1, between 1 and 2, 2 and 3; 5 and 6; 6 and 7; 9 and 10. Many local cases of unconformity and overlap of strata may occur within the limits of a system.

NOTES ON GEOLOGY.

Definition.—The science which investigates the History of the Earth. It treats of the nature and formation of the rocks which form the solid framework of the globe; of the agents which produce changes in these rocks; and of the history of the past life, whose remains (fossils) are buried in them.

The chief branches are:—

1.—Cosmical or Astronomical, relating to the earth's probable early condition, and its present form and motions.

2.—Petrographical, relating to the materials of the earth's crust, and the probable condition of its interior.

[(*a*) Mineralogy relates to the minerals.
(*b*) Lithology relates to the rocks or mineral aggregates.

3.—Dynamical, relating to the causes of change in the crust.

4.—Structural, relating to the architecture of the earth.

5.—Palæontological, relating to the fossilised forms of life.

6.—Stratigraphical or Historical, dealing with the chronology of the strata, and the succession of forms of life.

7.—Physiographical, relating to the history of present surface features and their causes.

The parts of the solid earth which man can examine, or about which he can reason by observations made at or near the earth's surface—form the *earth's crust*. This is composed of various rocks. A *rock* is a more or less extensive and natural accumulation of some one mineral, or oftener of a mixture of minerals, (for which see p. 21). It may be *hard* as granite, *soft* as clay, *loose* as sand, or *compacted* as sandstone.

If classed as to their general structure, rocks are:—

I.—*Stratified*, or arranged in strata, *i.e*, beds or layers, composed of various materials, arranged in or by water (Aqueous), or by wind (Aërial).

II.—*Unstratified*, in irregular masses, bosses, sheets, or veins, due to a former state of fusion (Igneous).

A ***Formation*** is a series of strata formed during one period of time, whilst the land and sea preserved a nearly fixed relative position. Successive oscillations of the land, here of elevation, there of subsidence, disturbed this relation of land and sea, producing new sea-lines, new cliffs, and new deposits of rock materials. Such different deposits or formations are distinguishable—

(*a*) by their relative position or order of super-position; for newer strata almost always overlie older.

(*b*) by differences of mineral composition, degree of coarseness, colour, &c. These may, however, vary much in the same formation, and be repeated in the same or in different formations. Hence they can rarely be depended on as tests of relative age in regions far apart.

(*c*) by their fossils, *i.e*, the remains of animals or plants buried in the earth by natural means, and often greatly altered by removal of old, and replacement by new matter (petrifaction).

The fossils must be more or less different in different deposits, since animals and plants change with changed conditions, and also with lapse of time [possibly owing to frequent creation of new forms, or more probably to evolution or gradual change of previous forms of life into others more suited to changed conditions of existence].

If classed as to their place and mode of formation strata are terrestrial, lacustrine, fluviatile, or marine.

Old Land Surfaces, with *Terrestrial deposits*, are marked by—
Tree-stumps in position as they grew, with tree-stems, leaves, fruits, land-shells (univalves), insects, &c., in the old soil round their roots—*e.g.*, the Purbeck "dirt beds," the many coal seams with the underclay underlying each.

Old Lake Beds with *Lacustrine deposits*
Old River Beds with *Fluviatile deposits* } are marked by—

(*a*) Beds of shell-marl or limestone, full of fresh-water shells—
Unio and Anodonta, Cyclas, Cyrena, Cypris, (bivalves);
Lymnæa, Paludina, Planorbis, Physa, (univalves), Melania.
e.g. Bembridge beds, Woolwich beds, Purbeck and Petworth marbles (of shells of *Paludina*).

(*b*) Clay containing these shells, or insects, leaves, fruits, &c.
e.g. Weald clay, Headon beds.

(*c*) Iron-stained sand, gravel, and conglomerate with fresh water and land plants, fishes, &c.
e.g. Hastings sands, Old Red and New Red Sandstones.
[Nagelflue of the Rhigi, 6,000 ft. thick, of Oligocene age].

N.B.—Salt Lakes and Lagoons are marked by chemical deposits.
e.g. Rock salt, Gypsum, together with marls.

Old Sea Bottoms with *Marine strata* are marked by—

Sea-weeds, (fucoids, corallines, &c.)
Sea-shells (especially these groups of Mollusca—Brachiopods, Lamellibranchs with one shell muscle, Gasteropods with notches or canals, Cephalopods).
Echinoderms, Corals and Foraminifera.

(1) Littoral or shore deposits by water-worn gravel, broken shells, pebbles, and conglomerates; by false-bedding due to varying currents; by rain-pittings, ripple-marks, sun-cracks; by foot-prints, and by shells of certain kinds found only on or near shores, *e.g.*, *Ostrea* or Oyster, *Cardium* or Cockle.

(2) Deeper water by fine mud and sand, without current bedding.

(3) Clear sea-water (usually far from land) by organic deposits, as *Limestones* made up of Foraminifera, Corals, Crinoids—*e.g*, Chalk, Oolite, Mountain and Wenlock Limestones.

Siliceous strata made up of Diatoms, Radiolarians, Sponge spicules.

The deep sea deposits of minute organisms are known as "ooze," *e.g.*, Foraminiferal or Globigerina ooze, Radiolarian and Diatomaceous ooze.

Ooze is a white or grey creamy mud, hardening into such rocks as Chalk, Tripoli and Dynamite Earth.

The stratified rocks, together with the products of contemporary volcanoes associated with them, have been arranged in the order of their production, first into Formations, then these into larger Systems formed during a particular Period.[*] About fifteen such Systems and Periods are named, (usually from districts where well developed) and are arranged into three or four still larger groups, as shown in the following table, which includes all the chief formations found in the British Isles, and Western Europe.

NOTE.—A bed or beds characterised by one or more distinctive fossils, is called the Zone or Horizon of that particular fossil, *e.g.*, Zones of various *Ammonites* in the Lias (see p. 8).

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[*] On geological maps the colours refer to the particular Formations which lie beneath the surface soil in each locality, or else to groups of such formations as explained in an index to the colours. Certain colours, usually reds, refer however to the particular rock material, if of Igneous origin, found there.

TABLE OF THE CHIEF FORMATIONS

IN WESTERN EUROPE.

Numbered in order of production, and placed in order of superposition.

• Denotes a distinct break—unconformity of strata, and change in fossils

IV.—POST-TERTIARY OR QUATERNARY. All the shells of sti living species.

15.—Recent or Human Period.

(2) Historic — Ages of iron and bronze.
(1) Pre-historic — Age of polished stone tools, &c. (Neolithi
Age of chipped stone tools (Palæolithi

14.—Pleistocene, Post-Pliocene or Glacial Period.

(3) Late Glacial. Britain re-elevated, and with larg glaciers (with terminal moraines).

(2) Mid-Glacial. Britain an archipelago; much floatin ice.

(1) Early Glacial. Britain and North Europe under a ice-sheet *(with ground moraine).*

III.—CAINOZOIC, OR TERTIARY. With some shells of still living species, but the mammals of extinct species.

13.—Pliocene, or Crag Period.

(2) Newer — Forest bed of Cromer and Chillesford beds.
Norwich Crag, or Mammaliferous Crag.

(1) Older — Red Crag.
White Crag, or Coralline Crag.

12.—Miocene Period. [Deposits of this age absent in Britain, unless the basalts and lignites of Antrim, Mull, &c., belong here, and perhaps the pipe-clay and lignite of Bovey].

NATURE OF THE DEPOSITS AND THE AREAS THEY COVER.

15.—The chief deposits are alluvium, or stream deposits, brick-earth (due to rain and weather acting on surface rocks), peat, loess, shell-beds, low-level river gravels, bone deposits in caves, *e.g.*, at Kent's Hole, Brixham; Kirkdale. Most high-level river gravels are of Palæolithic age. The works of early man are tools and weapons, pile-dwellings, in lakes, &c., shell-mounds, or kitchen middens, charred wood, &c. He may have existed in Western Europe in Mid-Glacial times (probably about 200,000 years ago).

14.—Raised beaches, "parallel roads," moraines, perched blocks, *Roches Moutonnées* (rounded ice-worn bosses of rock).

(3) Upper Boulder clay, including the great Chalky Boulder Clay covering the Eastern counties (Lincoln to London.)

(2) Sands, gravels (kames and eskers), erratic blocks, stratified clays, with marine Arctic shells.

(1) Lower Boulder clay or *Till* (a ground moraine), often resting on ice-worn rocks, and unstratified.

13.—The forest bed of the Norfolk coast consists of drifted roots, peat and clay. The Chillesford beds beneath contain many Arctic shells. The Norwich Crag is fluvio-marine, and contains large land mammals—elephant (mammoth), mastodon, rhinoceros, and hippopotamus. The older Crag deposits are chiefly beach sands with broken shells, mostly of existing species, some Arctic. At the base of both Red and White Crag lies a bed of nodules with much phosphate of lime (coprolites), and bones and teeth.

12.—Britain being then a land surface, no deposits were formed. In the Vienna and Mayence basins thick strata occur, with fossils pointing to a tropical climate. In North Greenland and Spitzbergen plant beds occur, and even a good coal, in 82° N. lat.

11.—Oligocene Period. (Often classed as Upper Eocene).

(1) Fluvio-marine beds in the Isle of Wight, viz.:—

Hempstead beds (= lower Miocene of Lyell.)
Bembridge marls and limestone.
Osborne beds.
Headon beds.

10.—Eocene Period, or Lower Tertiary (or Nummulitic Period).

(3) Upper—Bagshot sands (part), and *Barton clay.*
(2) Middle—Bagshot beds (part), and *Leaf-beds of Alum Bay, also Bracklesham beds.*
(1) Lower—
London clay and *Bognor beds.*
Woolwich and Reading beds (in both) with Oldhaven pebbles above and Thanet sands below.

In the Paris basins the deposits are very thick (*Calcaire Grossier*).

The nummulitic limestone (Middle Eocene) extends from the Pyrenees to Japan, and enters largely into the structure of the chief mountain chains—Alps, Himalayas (at 16,000 feet high).

The Pyramids of Egypt were built of this stone, formed almost *wholly of lentil-like shells* (*Nummulites*).

II.—MESOZOIC OR SECONDARY. With no forms of life still existing.

9.—Cretaceous Period.

Yellow chalk of Maestricht, Faxoe, &c. Aix-la-Chapelle. = *Danian stage.*

Upper
Upper Chalk (with flints) = *Senonian* ,,
Lower Chalk (no flints) = *Turonian* ,,
also Grey chalk
Chalk marl
Chloritic marl = *Cenomanian* ,,
Upper Greensand
Gault clay, &c. = *Gault stage.*

* * * * * * *

11.—The basalts of North-Western Europe—Iceland, Eifel, Auvergne, Antrim, Mull (3,000 feet thick), Skye, &c., with their interbedded lignites and leaf-beds, are probably of this age; and also the lignite of Bovey in Devon, and the brown coal of North Germany and of Switzerland (Molasse).

10.—The British Eocene beds occur only in the South-Eastern counties, lying in two synclinal depressions in the chalk, now separated into the London and Hampshire basins. (The italicised names refer to the latter). The fossils—palms, sharks, crocodiles, turtles, &c.—point to a warm climate.

Note.—A missing chapter in the Earth's history. Little is known of deposits in the great interval of time between the Cretaceous and Eocene periods.

There is little or no unconformity in the strata, though the lowest Eocene beds rest on an eroded surface of chalk, and a layer of green flints (Bullhead bed); but the great changes in the forms of life point to a great break in time, probably represented by deposits in U. S. America.

9.—*The Cretaceous beds vary greatly in nature, but in Western* Europe the upper part is chalk, a thick deposit of foraminiferal ooze, formed in a deep sea, and containing Echinoderms, Sponges, &c., which are often converted into flints. Beneath this are shallow water deposits, varying locally; hence the French names for the stages, founded on the fossils, are very superior to the English, founded on the deposits first described. The Chloritic marl (so-called Greensand) of Cambridge, contains coprolites. The red chalk of Hunstanton is of the same age. The Gault is usually a stiff blue clay, full of iron pyrites, and beautifully preserved fossils, especially Cephalopods—*Ammonites*, *Hamites*, &c.

Lower	Lower Greensand, or Neocomian, viz.:—		Neocomian stage.
	Folkestone beds Sandgate ,, Hythe ,, Atherfield clay	Speeton clay Upper Middle Lower occurring at Filey Bay, and at Tealby (Lincolnshire)	
	Wealden beds, viz.: Weald clay		
	Hastings' Sand (including Tunbridge Wells Sands, Ashdown Sands, &c.		

8.—**Jurassic Period,** including **Oolite and Lias.**

OOLITE.	*Upper*	Purbeck beds * * * *	= ***Purbeckian.***
		Portland stone and sand	= ***Portlandian.***
		Kimmeridge clay	= ***Kimmeridgian.***
	Middle	Coral rag (Coralline Oolite)	= ***Corallian.***
		Oxford clay and Kellaways rock	= ***Oxfordian.***
	Lower	Cornbrash	
		Forest marble & Bradford clay Great or Bath Oolite, with Stonesfield slate	= ***Great Oolite.***
		Fuller's earth	
		Inferior Oolite, pisolite, marl, &c.	

LIAS

Upper Lias, sands, &c.—Zones of *Ammonites Jurensis*, ***serpentinus, communis.***

Marlstone—Zones of *A.* ***spinatus, margaritatus, Davœi,*** (***Henleyi***), ***Ibex, Jamesoni.***

Lower Lias, clays, &c.—Zones of *A.* ***raricostatus, oxynotus, obtusus, Turneri, Bucklandi, angulatus, planorbis,*** **resting on *Avicula contorta* beds.**

The Neocomian beds of England are of two types—a Northern entirely marine, and a Southern, fluviatile below, (Wealden) passing into marine above (Lower Greensand). The Sandgate beds contain fuller's earth; and the Hythe beds yield "Kentish rag" building stone—a sandy limestone.

The Wealden strata (1,800 feet thick) are fresh water or estuarine, and were formed as a delta (at least 20,000 square miles in area), at the mouth of a great river from the North-West. They are confined to the Weald of Kent, Surrey and Sussex; the Isle of Wight and near Boulogne (200 miles from East to West). Fossils—Land plants and reptiles,—huge Saurians and winged Pterodactyls, &c.

8.—The Jura mountains and Alps largely consist of contorted rocks of this age, in folds of every degree of size.

The Jurassic system consists in Britain chiefly of blue clays and limestones, usually oolitic or pisolitic, and very rich in fossils. The Portland and Bath Oolites yield valuable freestones.

The Purbeck beds contain old soils ("dirt beds") with tree stumps, as they grew; also many insects and land mammals (twenty species) occur in the fresh-water deposits. These beds are often grouped with the Wealden.

The Solenhofen limestone, or 'lithographic slate,' from near Munich and of Kimmeridgian age, contains the oldest known bird, and also reptiles, fishes, crabs, insects, &c., in perfect preservation.

The Stonesfield slate—a sandy limestone used for roofing—contains many ferns, cycads, insects, reptiles, and mammals.

The Northampton sands, with ironstone, are of the age of the Great and Inferior Oolites.

Note.—The Lower Oolites to the South of Gloucester are marine, but pass into estuarine deposits to the North-East, near Northampton; and in Yorkshire, land and fresh-water deposits occur, including a small coal-field. Coal beds also occur at Brora, in Sutherland, of this age.

The Lias is remarkable for its abundant and well-preserved fossils. It was the "age of reptiles"—saurians, flying lizards, &c.; and cephalopods abounded—*Ammonites* (130 species), *Nautilus* (10 species), *Belemnites* (60 species).

The three formations are sub-divided into bands, or zones, each marked by characteristic species of Ammonites.

7.—Triassic and Rhætic Periods.

Rhætic or Penarth beds ("White, or Infra-Lias,") or *Avicula contorta* beds.

Upper—Keuper, or New Red Marl and sandstone.

Middle—[Muschelkalk—absent in Britain].

Lower—Bunter, or New Red Sandstone proper (containing pebble beds and breccia, in the Severn valley).

NOTE.—A missing chapter. A great stratigraphical and palæontological break occurs here, very marked in Germany, but less so in Britain, owing to the scanty fossils, and to the red colour of both series, which caused the name New Red Sandstone to be formerly applied to both.

I.—PALÆOZOIC OR PRIMARY. With ancient forms of life.

6.—Permian or Dyas Period.

Upper.—Red sandstones, clays and gypsum (no fossils.)

Middle.—Magnesian limestone, (Dolomite), *(Zechstein,)*
Marl slate, *(Kupferschiefer.)*

Lower.—Red sandstones, marls, breccias, *(Rothliegende).*

* * * * * *

5.—Carboniferous Period.

Upper.—Coal Measures with Pennant Grit at Bristol, &c., and Gannister beds in South Lancashire.

Middle.—Millstone grit, (Farewell or Moor Rock).

Lower.—	Carboniferous, or Mountain Limestone.	Yoredale shales and grits. The thick Limestone. Lower Limestone shale.

NOTE.—In Scotland, the Calciferous sandstone represents the last.

In the middle of this, sheets of porphyrites and tuffs occur all across the great central valley, and mark prodigious volcanic activity there in Lower Carboniferous times. Some of these sheets are 1,500 feet thick.

7.—The Rhætic are "passage beds," occuring as a thin band from North of Yorkshire to the Dorset coast, but best seen at Westbury-on-Severn and Penarth near Cardiff. In the Rhætic Alps the strata of this age are very thick.

The Keuper and Bunter, like most red rocks, contain few fossils. The former yields rock-salt and gypsum (lake deposits), and contains the oldest known Mammal (*Microlestes*).

The Muschelkalk of Germany is a limestone rich in marine fossils.

The marine Hallstadt and St. Cassian beds (on North and South side of East Alps) are of the Keuper age, and very rich in fossils which connect the fauna of Primary and Secondary rocks, *e.g.*, *Orthoceras* occurs with *Ammonites* and *Ceratites*.

Both the Trias and Permian formations of Western Europe were formed in inland seas or salt lakes of a large continent. Land plants and large Labyrinthodont (frog-like) reptiles are the chief fossils in both.

6.—Upper and Lower Permian beds are best seen in Cumberland.

	In W.	In N.E.
U.	600 feet	thin
M.	thin	600 feet
L.	3,000 ft.	thin.

The Middle group yields valuable building stone, found in a narrow band from South Shields to Nottingham.

The Lower group much resemble modern glacial drifts—ice-borne debris.

NOTE.—Horizontal strata of this age cover nearly all Russia.

.—The COAL MEASURES occur in numerous detached though once united coal fields (basins), and consist chiefly of sandstones, shales, limestone, coal, and Under-clay, (unstratified, soft or hard, even flinty clays beneath coal seams, containing *stigmaria*,—*i.e*, roots of land-plants which grew where found). In South Wales the series is nearly 12,000 feet thick, with about 80 seams of coal, together 120 feet thick. In South Scotland the series is nearly absent, but good coal and black-band ironstone occurs in the lower group. In South Stafford a "10-yard coal-seam" occurs.

The MILLSTONE GRIT contains little coal and few fossils.

The Yoredale Rocks in the Pennine Hills are 4,500 feet thick.

The LIMESTONE is 1,500 feet thick in South Wales, and in Ireland is 3,500 feet, "one of the largest masses of limestone in the world." It is formed chiefly of corals, encrinites, polyzoa, or other marine animals; and igneous rocks (contemporaneous basalts, (&c.,) are abundant in South Scotland and North England.

4.—Devonian Period, including OLD RED SANDSTONE.

U.—Pilton beds—slates, &c.	U.—Red and yellow sandstones, conglomerates.
M.—Ilfracombe beds—slates, limestones of South Devon.	M.—Marly sandstones, flagstones, (occurs only in North Scotland).
L.—Lynton beds—slates and *sandstones,*	L.—Cornstones, sandstones *and conglomerates,*
(Total thickness about 10,000 ft.)	*(thickness about 25,000 ft.)*

3.—Silurian Period.

Upper	Ludlow beds, (1,950 feet.)	Tilestones and Ledbury shales. Upper Ludlow rock. Aymestry limestone. Lower Ludlow rock.
	Wenlock beds, (Denbigh grits,) (1,600 feet.)	Wenlock and Dudley limestone. Wenlock shale and flags. Woolhope limestone and shale. Tarannon shale, (pale slates).
	U. Llandovery or May Hill sandstones, (1,500 ft.)	

* * * * * *

Lower	L. Llandovery group, (1,000 feet). Bala and Caradoc group, (6,000 to 12,000 feet). Llandeilo flags, (2,500 feet). Arenig (or Stiperstone) beds (4,000 feet), (including Skiddaw slates (12,000 feet).

* * * * * * *

2.—Cambrian Period.

Upper	Tremadoc slates, U. and L.	(1,000 feet).
	Lingula flags.	(5,000 feet).

NOTE.—Murchison included the Upper Cambrian with the Silurian; but Sedgwick included all the Lower Silurian with his Cambrian.

4.—The Devonian type is marine, and occurs in Britain only to south of the Bristol Channel, consisting there of grey and blue slates, schists, sandstones, and limestones rich in corals at Plymouth, Torquay; as also in the Eifel Limestone. The Old Red type occurs from the Bristol Channel, through Wales, Central and North-east Scotland to the Shetlands; and also largely in Ireland. Everywhere a great break occurs between the Upper and Lower groups. It consists of lake deposits (in lakes Orcadie, Lorne, Caledonia, Cheviot, and Welsh lake), and in Scotland often abounds in fish remains and land plants. There, too, interbedded volcanic rocks occur, more than 6,000 feet thick, and form the Pentland, Ochil, and Sidlaw hills, which are "the basal wrecks of extinct volcanoes."

The two types occur together in Russia, covering a vast area.

3.—Silurian strata cover a wider extent of the earth's surface, and are more uniform in nature of deposits and in fossils than any other group. They occur typically in Wales and border countries as grits and sandstones, shales and slates, with bands of limestone which swell to a great thickness, then thin out, but re-appear again and again. As a rule, they are now inclined, contorted, faulted and cleaved; or are even metamorphosed to schists as in the Highlands.

The "Tilestones," or Downton sandstone are mere passage beds; at their base is the Ludlow bone-bed full of fish scales, teeth, fin-spines, &c., and reaching 45 miles from North to South, and 30 from East to West. The Lower Ludlow shales contain the earliest known vertebrate—a fish *(Pteraspis Ludensis)*. The Wenlock L. is largely formed of corals and crinoids, and in it Trilobites, Orthoceratites, and Brachiopods are very abundant. It forms a ridge in Salop 20 miles long—"Wenlock Edge."

The Llandovery beds are often called Pentamerus beds, from the abundance of *P. lens* and *oblongus*.

The Bala beds and Arenigs contain, both in North Wales and Cumberland, vast piles of lavas and tuffs interstratified, which are several thousand feet thick, and mainly form the chief mountain peaks, as Snowdon, Cader Idris, Arenig.

2.—The Upper group (Olenidian from *Olenus*, a characteristic trilobite), consists of slates and flags, and contains abundant fossils, especially Trilobites and Brachiopods *(Lingulella)*.

.—**Cambrian Period** (*continued*).

Lower	Menevian beds of St. David's.		(600 feet).
	Longmynd beds:—		In South Wales, 4,000 ft.
	viz.	Llanberis slates,	In North Wales, 8,000 ft.
		Harlech grits,	In Shropshire, 25,000 ft.

.—*Archæan, or Pre-Cambrian Period or Periods.*

Lewisian, or Hebridean, or Fundamental Gneiss.

Laurentian of Canada,
Upper group, 10,000 ft. thick.
Lower group, 20,000 ft. at least.

Note.—In serpentinous limestone of latter occurs *Eozoon Canadense*, a supposed animal of the lowest class, (*Foraminifera*).

In European rocks no fossils have been found, but in Canada, besides *Eozoon*, there occurs much graphite and iron ores, both probably due to plants.

Caution.—There is no Azoic or Hypozoic Period known, for traces of life occur in the oldest rocks; nor is there any special Metamorphic System of strata, since formations of any age may become metamorphosed or altered; nor does granite everywhere underlie the series of stratified rocks as was once supposed. The oldest rocks known are of sedimentary origin, and therefore derived from still older rocks, no remains of which perhaps now exist. Certainly no trace of an original igneous crust remains. What Hutton wrote a century ago in the infancy of Geology, a modern geologist can still say—"In the economy of the world, I can find no traces of a beginning, no prospect of an end."

The Lower group (Paradoxidian from *Paradoxides*, another trilobite), contains few fossils, except near St. David's; a bed of conglomerate usually lies near the base. In North-west Scotland, a similar rock with breccia and red sandstone is 8,000 feet thick, resting on *roches moutonnées* (?) of Archæan gneiss, and possibly points to a Glacial period.

1.—The oldest known rocks are distinctly bedded, but highly crystalline schists and gneiss, due probably to metamorphism of sedimentary strata. These Pre-Cambrian rocks occur in the Outer Hebrides, (Lewis, &c.,) C. Wrath, St. David's, 18,000 feet thick, the Wrekin, Malverns, Charnwood Forest, North Wales, and Anglesea, in all these latter with much volcanic matter; also in Scandinavia and Central Europe. In the Dominion of Canada, two divisions occur, (1) Huronian resting on (2) Laurentian. This latter term is commonly extended to all Pre-Cambrian strata, including those in N.W. Scotland, Wales, &c.

Prof. Hull has estimated the total maximum thickness of stratified rocks at about 177,000 feet, or 33 miles, of which the Palæozoic form about 25 miles. From the thickness of the strata deposited, some idea may be formed of the relative duration of different periods.

		FEET.
IV.	**Recent and Post Pliocene**	?
III.	**Pliocene**	2,000
	Miocene	7,000
	Eocene	6,500
II.	**Cretaceous**	12,400
	Wealden	1,400
	Jurassic	5,000
	Triassic	6,760

	Palæozoic Periods.	FEET.
I.	**Permian**	4,000
	Carboniferous	21,000
	Devonian and Old Red Sandstone	25,000
	U. Silurian	4,000
	L. Silurian	27,000
	Cambrian	28,000
	Laurentian	32,750

I.—The PRIMARY STRATA are marked by Palæozoic or ancient forms of life, all the species and all but 16 genera then existing being now extinct, as also certain whole families, viz.:—Graptolites, Rugose Corals, Cystideans, Trilobites and Eurypterids (both Crustacean), Orthoceratites, and Labyrinthodont (or frog-like) reptiles. Crinoids or Encrinites (plant-like Echinoderms) and Brachiopod shells were then very abundant in number, and very varied in form. It was the Age of Brachiopods. The fishes had heterocercal (unequally-lobed) tails, but no true bony skeleton, though often covered with bony plates. The land plants were chiefly Ferns, giant Lycopods and Conifers.

Note—Entire absence of Flowering plants, Birds and Mammals.

II.—The SECONDARY STRATA are marked by Mesozoic forms, especially *Ammonites*, *Belemnites*, and allied Cephalopods. Brachiopod shells still abundant, but little varied, chiefly *Terebratula* and *Rhynchonella*. Peculiar forms are Saurian reptiles, often of huge size, and flying *Pterodactyls*. This was the Age of Reptiles. The fishes mostly had homocercal (equally-lobed) tails.

Note.—Mammals (chiefly marsupials) and Birds first occur—the former in the Trias, the latter in the Cretaceous.

III.—The TERTIARY STRATA are marked by Cainozoic, or recent forms, especially the higher vertebrates. The percentage of existing species gradually increases upwards, and gives name to the successive periods, *e.g.*—Eocene (dawn of recent species), Oligocene (few recent), Miocene (minority of recent), Pliocene (majority of recent), Pleistocene (most of recent species). *Nummulites* (a coin-like Foraminiferous shell) occurs here only. Birds and Mammals, as also Crabs, Crocodiles, Turtles, Gasteropod shells become abundant; and flowering plants are characteristic forms.

IV.—The POST TERTIARY Strata are marked by bone caves, and remains of man and his works—tools, weapons, &c.

ECONOMIC GEOLOGY.

On the Practical Uses of a Knowledge of Geology.

The useful applications of Geology are many and varied, especially in Agriculture, Architecture, Engineering, Manufacturing, Mining, and the Arts.

1.—It explains the causes which have produced the present surface features, and the necessary connection between these. It thus assists the **Landscape Gardener** and **Painter,** and the **Surveyor.**

2.—It explains the Fertility or the Barrenness of different soils and rocks, by reference to (1) their mineral and chemical composition and how defects in this, prejudicial to particular crops can be remedied, *e.g.*, when it is wise to add sand, or lime, or clay; or when most desirable to add guano or other manure; (2) their relative position, both as to the slope of the ground, and as to the dip of the strata. This will guide the direction and extent of both surface and sub soil drainage; (3) the porous and absorbent, or the non-porous and retentive nature of the sub-soil rocks. In these ways it may be of great use to the **Farmer** and **Agriculturist.**

3.—It explains the natural drainage of a district, both surface and subterranean: and it shows where Artesian wells are possible, and where fissures and faults exist. Such information is of great importance to the **Engineer** constructing canals, sinking wells, or seeking a water-supply for a canal or a town.

4.—To the **Architect** and **Builder** it affords indispensable information, as to (1) the composition of various rocks fit for particular uses, *e.g.*, for building-stone, for bricks, for mortar and cement, for tiles and slates. The way in which the rock considered has been affected by the weather, where exposed in cliffs and quarries, affords a valuable guide as to its durability; (2) the areas covered by rocks yielding these materials, and their relative position among other strata, and how best worked.

-To the **Road-maker** it is of great importance in gi him (1) as to choice of a line of road, so as to ensure its proper drainage, and prevent slipping. This will depend on the nature and succession of the strata and their dip; (2) as to road-metal—what rocks are obtainable, and what not;

what rocks are preferable, e.g., granite, greenstone, gneiss, quartzite, gravel, basalt, flint, chert, crystalline limestones; what are unsuitable, e.g., slates, shales, schists, most sandstones and earthy limestones such as oolite, chalk, and marl.

6.—To the **Engineer** making tunnels, cuttings and embankments, foundations for bridges, cutting canals and docks—it is most necessary that he should know:—

(1) the character of the rocks met with, especially whether hard or soft, permeable or not, to water.
(2) the succession of the strata in the district, and their thickness.
(3) the dip of the strata, and the direction of the drainage.

7.—To the **Manufacturer** it points out what supplies of Fossil Fuel—Peat, Lignite, Coal, Anthracite, Petroleum—are to be expected; and when it would be useless to seek for these. Vast sums of money have been wasted in sinking for Coal, where a geologist could have shown the improbability of its occurrence, or at least, within a working depth.

8.—To the **Miner** seeking metallic ores or gems, it teaches how to recognize these and the rocks usually associated with them; as also their usual modes of occurrence; and in the case of Lodes or Veins, which often abruptly cease owing to "faults," it shows where to seek for their reappearance.

Lastly.—To the **Student,** few subjects afford such a constant necessity for observation, comparison, and deduction; and hence, few are so well calculated to train the intellect in these its most valuable powers.

THE DISTRIBUTION OF VALUABLE MINERALS AND ROCKS.

NOTE "If we draw a slightly sinuous line from the mouth of the Tees through the centre of England to the mouth of the Exe, we should divide England into two totally dissimilar parts, in which the form and aspect of the ground, and the condition and employments of the people, were alike contrasted with each other. The part to the north-west of this line is chiefly Palæozoic ground, often wild, barren and mountainous, but in many places full of mineral wealth; the part to the south-east of it is Secondary and Tertiary ground, and generally soft and gentle in outline, with little or no wealth beneath the soil. The mining and manufacturing populations are to be found in the first district; the working people of the latter are chiefly agriculturalists."—DR. BUCKLAND

COAL is of 3 chief kinds:—1 Anthracite or *Stone Coal* (used only in furnaces and for steam engines): occurs in South Wales, Glasgow, Kilkenny, and Pennsylvania. 2. Ordinary Coal *(miscalled bituminous), including Cannel, Jet; Boghead Coal is a bituminous shale, found in Scotland, from which oil is distilled.* 3. Lignite or *Brown Coal*, abundant in Central Europe, Punjab; and found also in Devon, Antrim, &c.

Coal, usually associated with rich iron ores, occurs in many detached areas, usually geological basins, called **Coal Fields.** Those in Britain yield 135 millions of tons of coal, and 7 millions of tons of iron annually. The chief are:—

1. *The Forth and Clyde*, including *Ayr* and *Edinburgh*. 2. *Newcastle*. 3. *Whitehaven*. 4. *Lancashire and Cheshire*. 5. *Yorkshire*. 6. *North Stafford* or "Potteries." 7. *South Stafford* or "Black Country." 8. *Bristol*. 9. *Dean Forest*. 10. *South Wales* (900 square miles). The three latter were doubtless once united, and Ramsay thinks much coal still lies buried under newer strata in and around the Severn estuary. Coal occurs in 17 counties of Ireland, but nowhere in abundance.

Foreign Coalfields occur in Belgium, *at Liege*, &c., North France, Rhine Prussia, Silesia, North-West Spain, India *West of Calcutta*, Borneo and Formosa, North America. [See Maps at end of book]. "Nowhere is the Coal formation more extensively displayed than in the United States, and in no part of the world are its beds of greater thickness, more convenient for working, or more valuable in quality."—*(Dana)*. It occurs there in the following areas: 1. *Pennsylvania to Alabama* (720 by 280 miles). The Pittsburg seam alone covers 14,000 square miles, and is 10 feet thick. 2. *Illinois, Indiana, &c.* Each of these areas is as large as England and Wales. 3. *Missouri*. 4. *Michigan*. 5. *Rhode Island*. In Nova Scotia and New Brunswick a coal area occurs of 10,000 square miles. In Cape Breton Island; and in Canada, to the East of the Rocky Mountains, coal is also abundant.

The above coals are of **Carboniferous age,** but coal occurs of other periods, *e.g.*—

Of **Keuper** age, at Richmond, U.S.A. (26 miles by 4 to 12), the main seam being 30 to 40 feet thick, and of the best quality.

Of **Oolitic** age, at Brora in North of Scotland, South of India, Labuan, Phillippines.

Of **Cretaceous** age, in Vancouver Island and the Rocky Mountains district from New Mexico to Canada. (The vast deposits here are Lignitic, and may partly be of Eocene age.)

Of **Miocene** age, in North Greenland, North Germany, Switzerland, Bovey in Devon. Most of this is Lignite, and still shows woody structure.

GRAPHITE, Plumbago, or Black Lead is nearly pure Carbon, and often only an extreme form of Anthracite, and so of coal. It occurs in Cumberland, Cornwall, Spain, Bohemia, Greenland, Finland, Norway, and especially Canada; usually in slates, schists, gneiss, granite. The chief supply is from Ceylon.

IRON is everywhere diffused, and rich deposits occur in most coal fields, as also in **Laurentian** strata in Canada; in **Silurian** strata in Mid-Sweden; in **Great Oolite** Sands at Northampton; in **Middle Lias** at Cleveland, Yorkshire. (Formerly it was largely worked in South-East England from the Wealden Sands.)

Iron Pyrites, the chief source of Sulphur, occurs very abundantly, especially in the Coal Measures. 50,000 tons are raised yearly in Britain, and 500,000 tons are imported from Spain, &c.

GOLD *has been detected in almost every country and every kind of rock, especially slates and schists abounding in quartz veins.* It occurs both in the veins and in the rock near the veins, and still more in the detritus—gravel or alluvium—derived from these. It is usually in a native state in crystals, grains or nuggets.

The Romans worked extensive gold mines in Caermarthen, and gold occurs there and in Wicklow, Lead hills (Scotland), &c. It is worked in Hungary and Transylvania, Piedmont, the valleys of the Upper Rhine and Danube, Sweden, Russia in the Ural district. Siberia in the Altaï Chain, Thibet, Yunnan in China, Borneo, &c. But the chief supplies are obtained from **Australia**, chiefly South-East part, Tasmania, New Zealand; and North America, both the East side from Nova Scotia to Georgia, and the West side from British Columbia to Mexico—above all in **California**. In South America, **Brazil**—*Minas Geraes*, Chili, Peru, New Granada and Nicaragua; in Africa, the Transvaal and Guinea Coast are important sources.

SILVER occurs in Britain, chiefly in Lead ores, as at *Alston Moor*, also in Spain, Saxony, Hartz Mountains, Austria, Hungary, Asia Minor, Siberia, Nevada, U.S.A., but most abundantly in Mexico, at *Guanaxuato*, and the Andes of Peru and Bolivia at *Pasco*, *Potosi*; and Chili at *Copiapo*.

PLATINUM is found only in alluvial deposits, and only in the Ural region, in Brazil, and in New Granada.

Mercury—(Quicksilver) occurs in Spain at *Almaden*, Austria at *Idria*, the Palatinate, Tuscany, Ceylon, China, Japan, California, Mexico, Peru. Of 4,000 tons raised yearly, California yields nearly two-thirds, and Spain one-third.

Tin occurs in Cornwall and Devon (both in lodes and in stream deposits), in Saxony, Bohemia, Spain, Siberia, Bolivia; but especially in Tenasserim and Banca Island in South-East Asia.

Copper occurs native in huge masses, up to 1 ton in weight, near L. Superior, and largely in S. America and Siberia. Various ores occur in veins in Cornwall, Devon, N. Wales, Saxony, &c.

Note.—*Swansea* is the head-quarters of copper and tin smelting.

The other metals are too abundant and wide-spread to be noticed here. [*For important ores, see p. 28.*]

Rock Salt occurs, usually with red clays and Gypsum, of Keuper age—in Cheshire at Northwich and Nantwich; in Worcester at *Droitwich; in Stafford at Shirleywich; in Durham; near* Belfast; *also in Spain; Austrian Poland at Wieliczska,* where 50,000 tons are raised yearly, and the district for 600 miles on each side of the Carpathians, which is incomparably rich in salt; Salzburg, Tyrol, Syria, Punjab, China, United States, Andes, &c.

Slate of **Cambrian** age is worked in North Wales at *Penrhyn*, *Llanberis*.

Of **L. Silurian** age at *Ffestiniog* in Merioneth; and in Cumberland.

In **Wenlock Shale** near *Llangollen*; of **Devonian age** in in Cornwall and Devon.

Slates are also obtained in Scotland, Ireland, of **Silurian age**; and in Spain, Italy, France, United States, of various ages.

Tilestones—thin-bedded sandstones, used for roofing and flagging—are found in several formations, from Upper Silurian to Wealden, and much used in Forfar, Dumfries, Yorkshire, Gloucestershire (on the Cotswold Hills).

Kaolin, or Porcelain Clay, derived from decomposed Felspar, is dug in Cornwall, Saxony, China, Japan, Delaware.

Marble, or Crystalline Limestone for Statuary, is got chiefly from *Carrara*, near Spezzia in Italy, and is of **Oolitic age.**

The "Encrinital Marble" of Derbyshire and Yorkshire is of **Carboniferous age.** It is much used for chimney-pieces.

The "Irish Green Marble" of Connemara: the Serpentine rock of the Lizard, both chiefly of Serpentine (see p. 27); the "Cipolino" and "Ruin Marble" of Italy, are all celebrated.

LIMESTONES used for building occur in Britain—

Of **Devonian age** at *Plymouth* and *Torquay*.

Of **Carboniferous age** in Derbyshire, Gloucestershire, &c.

Of **Permian** age, the Magnesian L. used for York Minster, and the Houses of Parliament (quarried at *Bolsover*).

Of **Oolitic age** at *Portland*, *Bath*, *Box*, Cotswold Hills, at *Stroud*, *Painswick*, *Cheltenham*, Lincoln and York Wolds; also the Purbeck limestone and marble.

Of **Wealden age,** the Petworth or Sussex marble used for church decoration. [For its origin, see p. 2.]

Of **Cretaceous age,** the Kentish rag, a hard, sandy greenish L. quarried in the Hythe beds at *Maidstone*, *Hythe*, &c., and the Totternhoe Stone of Cambridgeshire, of Lower Chalk age.

Of **Eocene age,** the Nummulitic L. of the continent is extensively used in South Europe, Syria, Egypt, &c.

Of **Oligocene age,** the Bembridge L. of the Isle of Wight. [For its origin, see p. 2.]

LIME is prepared by burning in kilns any of the above Limestones, as also others unfit for building, e.g., Wenlock L. Marlstone, Chalk. If impure from clay (Argillaceous L.,) hydraulic lime is obtained, used for cement, which will set under water.

SEPTARIA are nodules of clay with fissures (due to contraction in drying), since filled with Carbonate of Lime, which forms *septa*. They occur in the London clay, Lias, Ludlow Rock (as huge ball-stones). Formerly they were sought for making cement and hydraulic mortar.

COPROLITES are concretions of Phosphate of Lime, derived from decay of animals, or possibly of sea-weeds, and often investing animal remains. They are of great value in the preparation of artificial manure. In 1875, in 3 counties only, 250,000 tons were raised. Beds of these occur in—1. The **Red Crag,** and 2. **Coralline Crag,** of Suffolk. 3. **Upper Greensand** of Cambridge. 4. **Gault.** 5. **Upper Neocomian.** 6. **Bala beds** of North Wales. [7. Tertiary strata of Georgia and the Carolinas]. Phosphatic deposits occur also as Apatite, and are largely worked in the gneiss of Canada and Norway.

SANDSTONES used for building and flagging, are mostly—

Of **Old Red** or **Devonian age,** as at *Chepstow*, *Dundee*, *Caithness*, *Cork*, *Kerry*.

Of **Carboniferous age,** as the Yorkshire flags, Yoredale rocks, Millstone grit, Pennant grit, Craigleith or Calciferous sandstone of Edinburgh.

Of **Permian age,** as at Penrith, St. Bees, Furness Abbey, &c.

Of **Triassic age,** as the L. Keuper rock of the Midland counties. The Bunter Sandstone is too friable for building.

Of Lower **Cretaceous age,** as the Hastings sand, Bargate stone, Folkestone beds of the Lower Greensand.

Sandstones of **Tertiary age** are very important in South Europe, and form a considerable part of the Himalayas.

GRANITE of various colours and degrees of coarseness, is largely used for sea-walls, docks, bridges, houses, &c.; and when polished for decoration, especially that from Aberdeen (*grey*), Peterhead (*red*), Mull (*pink*), Shap (*porphyritic*), Mount Sorel (*rose pink*) Jersey (*dark blue*), Dartmoor (*grey or white*). This and other Igneous rocks are largely used for road metal, locally and in most large towns.

There are two Elementary bodies, not metals, which occur native, and may be noticed here.

The DIAMOND—pure Carbon—found in crystals, and in water-worn grains in sand and gravel, in sandstone and itacolumite, and in certain volcanic debris. The chief sources are—South Africa at *Kimberley*, Brazil, India, Australia.

SULPHUR is found in thick beds with gypsum, in marine Tertiary strata in Sicily, Naples and Tuscany; also in the geyser regions of Iceland and New Zealand, and more or less in most other volcanic regions.

ON THE MINERALS FORMING ROCKS.

"A mineral is a uniform (homogeneous) substance, formed without the agency of man, and under conditions in which neither animal nor vegetable life has taken part."—*Rutley.* Usually a mineral has a definite chemical composition, and a proper form (or a series of related forms), usually that of a crystal, with plane faces and angles whose value is constant for the same species of mineral. Minerals can grow only by the addition of new matter on the exterior—*i.e.*, by accretion.

Characters by which to distinguish minerals:—1. Form; 2. Composition; 3. Density; 4. Hardness; 5. Cleavage; 6. Fracture; 7. Colour, Lustre, or other effect of light; 8. Streak or colour of scratch, or of mark made on paper, &c.; 9. Taste or Smell.

NOTE.—*These terms are more or less used in reference to rocks as well as minerals.*

1. The form, if a crystal, is usually a prism or a pyramid or a combination of such, and is referred to one of six systems, viz.: I. Cubic; II. Tetragonal; III. Hexagonal; IV. Rhombic or Prismatic; V. Monoclinic; VI. Triclinic. Other forms are *scaly, columnar, nodular, granular, reniform, mammillated. Amorphous* means the absence of any definite form.

2. The composition is expressed by stating the elements or chemical compounds present, or more briefly by a chemical formula.

3. The Density or Specific Gravity is expressed by a number which compares it with Water as unity. Most rock-forming minerals vary from 2 to 3; metallic ores may be 8 or 10, and native metals even 21. To find it requires weighing in air and in water.

4. The hardness, H, is readily tested by a knife or file, or by finding what minerals it can scratch, and what can scratch it. Such test minerals form a

SCALE OF HARDNESS.

(1) TALC, *soft cleavable variety.*
(2) ROCK SALT, *or else*
GYPSUM *(variety Selenite).*
[2·3. The finger nail].
(3) CALC SPAR OR CALCITE.
(4) FLUOR SPAR
(5) APATITE [*or else Window Glass*]
The above are too soft for gems.

(6) ORTHOCLASE FELSPAR
[or a good steel knife]
(7) QUARTZ OR FLINT
(8) TOPAZ.
(9) CORUNDUM, *or Emery,*
(Sapphire or Emerald).
(10) DIAMOND.
The above are all cut as gems.

5. Cleavage is a tendency to split along definite planes, and is well-marked in Mica, Diallage, Selenite, Calc spar, &c.

N.B.—In Clay Slate, a similar structure, due to pressure, is well seen.

6. Fracture or form of a broken surface may be *conchoidal* with curved face, as in flint, obsidian; *even* or flat; *rough* or *hackly*; or *earthy*, as in chalk, clay, &c.

7. Colour is little to be depended on, as it may vary greatly with slight impurities, or change on exposure to the weather, or to the action of water. Red, Yellow, Brown, is usually caused by Oxides of Iron; Green often by Silicate of Iron; Black by Magnetic Oxide of Iron. Thus Iron is the great colouring agent of the world.

8. Streak is most useful in distinguishing the oxides of Iron. (See p. 28).

CHEMICAL COMPOSITION OF THE EARTH.

Out of about 66 known Chemical Elements, mostly metals, 12 only occur abundantly, making up 999 parts in 1,000 of the Earth's crust.

The percentage amounts of these given in brackets in the table, can only be estimated roughly from analysis of the known rocks of the crust; the materials of the interior may be very different in proportion if not in kind.

NON-METALS				METALS.		
(O.)	**Oxygen,** forming	48 p.c		**(Al.)**	**Aluminium**	8 per cent.
(Si.)	**Silicon** ,,	29 ,,		**(Fe.)**	**Iron**	6 ,,
(H.)	**Hydrogen** ,,	0.2 ,,		**(Ca.)**	**Calcium**	3 ,,
(C.)	**Carbon**	These, with all other elements not named, only form 0.3 p.c.		**(Mg.)**	**Magnesium**	1.5 ,,
(S.)	**Sulphur**			**(Na.)**	**Sodium**	2 ,,
(Cl.)	**Chlorine**			**(K.)**	**Potassium**	2 ,,

Thus O. forms nearly one-half, and Si. nearly one-third the whole Earth's crust; their compound Silica forms nearly two-thirds of the whole material of known rocks.

The union of any two elements produces a binary compound, as—

H_2O. Hydrogen oxide, or Water (forming 2.7 p.c.)
$Si\,O_2$ Silicon dioxide, or Silica (forming 62 p.c.)
$C\,O_2$ Carbon dioxide, or Carbonic acid gas.
$Fe\,S_2$ Ferric disulphide, or Iron Pyrites or Mundic.

The union of a metal with Oxygen usually produces a Base, as—

Al_2O_3	Alumina, forming	15 p.c.		K_2O.	Potash, forming	2.4 p.c.
$Ca\,O$.	Lime, ,,	4.2 ,,		Na_2O.	Soda ,,	2.7 ,,
$Mg\,O$.	Magnesia ,,	2.5 ,,		$Fe\,O$.	Iron protoxide	8.3
				Fe_2O_3	Iron peroxide	

The union of a non-metal with H., or with H. and O., usually produces an acid, as:—$H\,Cl$. Hydrochloric acid; $H_2S\,O_4$ Sulphuric acid; $H_2Si\,O_3$ Silicic acid.

The action of an Acid on a Base produces a Salt, as—$Na\,Cl$. Sodium Chloride (Common Salt); $Ca\,CO_3$ Carbonate of Lime or Calcium Carbonate, which forms all Limestones.

Most minerals are Salts; by far the greater number which form rocks being Silicates of one of the above-named bases or mixtures of them; a few are Carbonates, Sulphates, Sulphides, Chlorides, &c.

If water be essentially present in a mineral, this is said to be Hydrous or Hydrated, *e.g.*, Kaolin (and Clay), a Hydrated Bisilicate of Alumina; Gypsum; Opal; Serpentine.

THE CHIEF ROCK-FORMING MINERALS ARE:—

1.—Quartz, *H.7, composed of Silica, i.e., Silicon oxide ($Si\,O_2$); Crystals (of System III.) in 6-sided prisms with pyramids, but usually imperfect in rocks, mere glassy lumps.*

Varieties are:—*Rock-crystal, Amethyst, Cairngorm, Aventurine*; *Cat's eye.*

Uncrystallised forms are *Chalcedony, Agate, Onyx, Flint, Chert.*

Opaque forms are *Jasper;* Hydrated forms *Opal* and *Sinter* (*Geyserite*).

Most Sands, Gravels and Pebbles are less pure forms of Quartz.

2.—Felspar, H.6, composed of Silicate of Alumina, together with Silicate of Potash, Soda, or Lime, and often coloured by Iron oxides; Crystals (V. or VI.) usually long brick-like prisms. There are several species of Felspar, besides varieties.

(1) **Orthoclase,** or Potash F. $[K_2O, Al_2O_3, 6\,(Si\,O_2).,]$ abundant in granite. Sanidine is a clear glassy variety, very abundant in Acidic Volcanic rocks, *e.g.*, Trachyte.

Other varieties are Adularia, Sunstone, Moonstone, Amazon stone.

(2) **Oliogoclase** is a Soda-Lime F., like the last rich in Silica.

It is possibly a mixture (3·1) of two other rarer kinds:—

(3) Albite or Soda F., often found in granite, syenite, and diorite.

(4) Anorthite or Lime F., found in some old lavas and diorites.

(5) **Labradorite** is a Lime-Soda F. and poor in Silica.

It is possibly a mixture (1.3) of the last two kinds.

It is soluble in acids, and rarely occurs with Quartz or Orthoclase.

All these except the first are Plagioclase (System VI Triclinic), known from Orthoclase by the oblique cleavage, and fine parallel lines due to repeated twinning of the crystals.

2a.—*Nepheline* and *Leucite* are minerals, similar in composition, but not in form, to Felspars, which often take the place of Felspars in Vesuvian and other Lavas, but are not known in Great Britain. *Nosean, Hauyne* and *Epidote* may be grouped with them. *Zeolites* are hydrated minerals of similar composition, and easily melting, hence their name.

3.—Hornblende, H.5-6, of Silicates of Magnesia and Lime, with some Alumina and oxides of Iron; **a heavy usually dark green or black mineral.** Varieties are *Actinolite*, *T* [illegible] **, all in long, slender (needle-like) crystals.**

4.—Augite resembles Hornblende in hardness, composition, colours and general forms, but the angles of the crystals and the cleavages differ. Varieties are *Diallage* and *Bronzite*, both foliated like Mica, but harder, and with metallic lustre.

N.B.—Hornblende occurs associated with free Quartz, or with Orthoclase, chiefly in the older rocks. Augite has rarely been found with either of these, and occurs in the newer rocks.

4a.—*Olivine*, H.7. is similar to Augite in general composition, and occurs with it in olive-green masses in Basalts, many Meteorites, &c.

5.—Mica, H.2-3, includes several soft minerals easily splitting into thin elastic flakes, owing to the very perfect basal cleavage.

(1) *Muscovite or Potash Mica*, used for lanterns, gas covers, &c. (IV.) Hydrated forms are *Damourite*, *Margarodite*, *Sericite*, &c., abundant in the lustrous schists of the Alps, &c.

(2) *Lepidolite or Lithia Mica*, occurs in small pinkish or lilac scales.

(3) *Biotite or Magnesian Mica*, nearly black in colour. (III.) Common in Lavas, but rare in Granitic rocks and Schist.

6.—Talc, H.1. and **Chlorite** are very soft hydrated Silicates of Magnesia, &c., greenish grey, and greasy to the touch.

6a.—Serpentine is harder, and often veined and mottled green, red, brown. It is often altered Olivine, and occurs as a rock, at the Lizard, &c.

Certain other minerals occur largely, not only in scattered crystals, but often form extensive rocks of Aqueous origin.

7.—Calcite or **Calc Spar,** H.3, of Carbonate of Lime ($Ca\,CO_3$). Crystals (III.) in rhombs or pyramids, soft, effervescing with cold acid.

Iceland spar, Dog-tooth spar, Marble or Crystalline Limestone.

All true Marbles and Limestones consist of the same material.

7a.—*Aragonite* (IV.) has the same composition, but is harder and less common.

8.—Dolomite, or Bitter spar (III.) H.4, of Carbonates of Lime and Magnesia; occurs as a rock called Magnesian Limestone, valuable for building. Cold acid scarcely acts upon it.

9.—Selenite, (V.) H.2, easily cleaving into soft, inelastic flakes; of hydrated Sulphate of Lime; occurs in beds as *Gypsum*, often fibrous as *Satin Spar*, or veined like Marble as *Alabaster*. This is the source of Plaster of Paris, and of writing Chalk.

10.—Graphite or Black lead, Anthracite or Stone coal, ordinary Coal (miscalled bituminous), Cannel, Jet, and Lignite or Wood Coal are imperfect minerals of vegetable origin, composed chiefly of Carbon with some earthy matter. [See p. 18].

11.—Bitumen or Mineral Tar (with Petroleum, Naphtha, Asphalt, &c.,) is a mineral, often liquid, composed of Carbon and Hydrogen. It often impregnates shales, as in the valuable Torbane Hill mineral, or Boghead coal.

12.—The following compounds of **Iron** are common in or as *Rocks:*—

(1) ***Magnetite*** *or Loadstone ($Fe_3 O_4$) occurs in black grains or fine dust in almost all Igneous rocks; also in crystals (I.) and in large hill masses. Powder and Streak black.*

(2) **Hæmatite** or Specular Iron (Fe_2O_3) is very common as red stains in rocks and minerals, as a red powder (reddle), as also in crystals (III.) (iron glance), scales (iron mica), and in rounded masses lining cavities, or even forming hills. Powder and Streak blood-red.

(3) **Limonite** is a brown hydrated form of the above oxides (Fe_2O_3, H_2O). It causes the brown and yellow stains on weathered rocks. *Bog Iron-ore* and brown and yellow *Ochres* are varieties. Powder and Streak brown.

(4) **Chalybite** or **Siderite** is Carbonate of Iron ($Fe CO_3$), and occurs as *Clay Ironstone* in thick beds, and in nodules often Septarian, in the Coal Measures, Middle Lias and other clay formations.

The above are all valuable ores of iron, when occuring in mass.

(5) **Titaniferous Iron-ore** or Ilmenite ($Fe TiO_3$, Fe_2O_3) often occurs with Magnetite, as grains in Basalts, &c., or even in veins or beds; and as Titanic iron sand in Victoria, New Zealand, the River Mersey, &c.

(6) **Glauconite** is a Silicate of Iron and Potash, and gives the green colour to the Greensands, Chloritic Marl, and Chlorite.

(7) **Iron Pyrites** is Sulphide of Iron ($Fe S_2$), and occurs in brass-yellow cubes (I.), in nodules with a radiate structure and in grains. Fossils are often pyritized by replacement or by encrustation. It is an ore of Sulphur.

The ores of most other metals occur in Veins or Lodes with various Spars, *e.g.*, Fluor, Calcspar, Quartz, Barytes. The commonest are:—

Copper.—Copper Pyrites (Cu_2S, Fe_2S_3) darker and softer than Iron Pyrites; Ruby-Copper (Cu_2O); Malachite ($Cu CO_3 + Cu H_2O_2$).

Lead.—Galena ($Pb S$) resembles Lead, but occurs in very brittle cubes.

Zinc.—Blende ($Zn S$) and Calamine ($Zn CO_3$).

Tin.—Tinstone or Cassiterite ($Sn O_2$).

Gold—occurs native only, and usually with Quartz. [See page 20].

PETROGRAPHY—THE STUDY OF ROCKS.

Also termed by different writers PETROLOGY and LITHOLOGY.

Rocks are aggregations of minerals, either as loose incoherent grains, *e.g.*, blown sand; or as coherent crystals or grains, angular or rounded, and cemented by crystalline or by amorphous matter. The usual cement is either Silica, Felspathic matter, Carbonate of Lime, Carbonate of Iron, or Peroxide of Iron. More rarely there is no perceptible cement at all.

Some rocks appear to be uniform and structureless to the eye, as some Quartzites, and many glassy Volcanic rocks. These latter, when examined in thin slices under the Microscope, show fine dusty mattter (microliths), crystallites, and small crystals, embedded in a glassy matrix or base.

The original source of all rock material was the solidification of the molten mass of the primitive earth, owing to loss of heat by radiation into space. The destruction by denudation of this original crust of Igneous rocks afforded the materials for the early Sedimentary rocks; and these again, with Igneous rocks of later origin, the materials for all subsequently formed rocks of sedimentary origin.

Rocks may be named and classified according to:—

1.—Their **Chemical composition,** *e.g.*, Siliceous, Calcareous, Carbonaceous.

It is usual to classify Igneous rocks, whatever their structure' into—

A. Acidic—containing more than 60 per cent. of Silica or Silicic acid.

B. Basic—with less Silica than this, but more of the heavy bases.

Some writers make 4 classes, the above two, and also the following,—

C. Intermediate—with from 55 to 66 per cent. of Silica, *e.g.*, Syenite, Diorite.

D. Ultrabasic—with less than 45 per cent. of Silica, *e.g.*, Peridotite, Corsite.

This classification arose out of Durocher's theory that all Igneous rocks have been derived from one or other of two magmas or layers of molten matter lying in distinct zones beneath the solid crust of the earth.

2.—Their **Mineralogical composition,** *e.g.*, Quartzose, Felspathic, Augitic.

3.—Their **Mode of Origin,** viz.:—I. IGNEOUS or Eruptive.
II. AQUEOUS or Sedimentary or Derivative.
III. METAMORPHIC or Altered.

4.—Their **General Structure,** viz.:—I. UNSTRATIFIED or Massive.
II. STRATIFIED or Bedded. III. FOLIATED or Schistose.

5.—Their **Minuter Structure,** as seen even in hand specimens.
I. CRYSTALLINE, all or chiefly of crystals, *e.g.*, Granite, Gneiss, Marble.
II. NON-CRYSTALLINE, Clastic, *i.e.*, Fragmental, *e.g.*, Sand, Clay, Coal, Chalk.

I.—The CRYSTALLINE ROCKS, classed as to their general structure, are—

(1) **Massive**—in irregular masses, sheets, veins, dykes, as in nearly all Igneous rocks, *e.g.*, Granite, Lavas.

(2) **Foliated**—in irregular alternating layers of different minerals, as in Mica Schist, Talc Schist, Quartz Schiefer, Gneiss.

(3) **Stratified**—as in White Marble, Quartzite, Dolomite.

The minuter structure may be
(*a*) Wholly (or Holo), crystalline, *e.g.*, Granite, Gabbro.
(*b*) Semi-crystalline, with some glassy base, *e.g.*, Trachyte.
(*c*) Vitreous or Glassy, *e.g.*, Obsidian, Pitchstone, Tachylyte.

Varieties of the latter structure are Trichitic, Microlitic, Sphærulitic, Perlitic, Fluidal, Banded; the two latter due to irregular flow of lava.

NOTE.—Rocks with the same composition are often extremely unlike to the eye, e.g., Granite, Felstone, Obsidian. The texture of a crystalline rock is of great importance, since it shows the conditions under which it was formed; e.g., the pressure, rapidity of cooling, place or depth of solidification.

II.—The NON-CRYSTALLINE or CLASTIC ROCKS may be classed as to either their—

(*a*) Origin
(1) Of the debris of older rocks—**Mechanically formed.**
(2) Of the remains of plants or of animals—**Organically derived.**
(3) Of precipitates from solutions—**Chemically formed.**

(*b*) Composition, *e.g.* **Arenaceous,** sands, sandstones, grits, breccias
Argillaceous—clays, shales, slates, clunch, brick earth.
Calcareous—limestones, marble, chalk, dolomite.
Carbonaceous—coal, anthracite, graphite, peat, lignite.

THE CRYSTALLINE, MASSIVE, OR IGNEOUS ROCKS.

The denser and more perfectly crystalline forms of Igneous rocks—without glass, scoriæ, or ash—are called PLUTONIC or Hypogene, because probably solidified at great depths beneath the surface. The more glassy and semi-crystalline forms—often scoriaceous, and with ashes, tuffs or cemented ashes, and amygdaloids—are called VOLCANIC, because probably erupted at or near the surface. Some of the latter, of intermediate character, were formerly called Trappean rocks or TRAPS, *e.g.*, Basalt, Felstone, Greenstone.

NOTE.—The minerals usually present in each are denoted by the initial letter, this being enclosed in brackets where non-essential or secondary.

Q. means Quartz; **F**(1.) Orthoclase Felspar; **F**(2.) Oligoclase; **F**(5.) Labradorite; **M.** Mica; **H.** Hornblende; **A.** Augite.

A. ACIDIC GROUP, composed of highly silicated Felspar, together with free Silica as Quartz, except in the Intermediate group.

These are relatively light (S.G. about 2.5) and infusible; and contain about 74 per cent. of Silica (66 to 80), 12 of Alumina, 7 of Potash and Soda, 2 of Lime and Magnesia, and 3 of the heavy metallic oxides.

The chief Plutonic rocks containing excess of Silica, are:—

Granite of **F**(1.) **Q. M.** (also often F(2.) and Iron oxides).

The Felspar forms the large crystals, and is either a dull white, owing to *kaolinisation*, or tinted red, pink, &c., by Iron oxides. The Mica *is Muscovite varying from white to black. The Quartz is usually seen as glassy lumps often moulded on the other minerals; and possibly deposited from solution in hot water, after the other minerals had been formed in the pasty mass, for the quartz is full of fluid cavities. This would give to granite an Aqueo-Igneous origin due to Hydrothermal action. Probably many granites are due to intense metamorphism of sedimentary rocks, and so are but an extreme form of gneiss, into which it is often seen to pass imperceptibly. The depth of origin has been supposed to vary from three to twelve miles.*

Granitite has pink Orthoclase, much Oligoclase and little Quartz.

Granulite has red Garnet, and no Mica. It is really a Schist.

Greisen is chiefly Quartz, with Mica but no Felspar.

Protogine has no Quartz, but much Hydrous Mica, and Talc.

Pegmatite consists of very large crystals, in veins.

Graphic Granite is of Q. and F. arranged in layers like writing.

Hornblendic Granite contains H. as well as F. Q. M.

Syenitic Granite as in *Cleopatra's Needle*, of F(1). Q. H. but no **M.**

Syenite proper, of **F** (1). and **H.** but no free Silica ∴ Intermediate.

Quartz Felsite or Quartz Porphyry contains crystals of Q, in a fine-grained semi-crystalline or felsitic base of F. Q. (M. H.)

Felstone of Q. and F (1). If very fine grained it is **Felsite.**

The chief Volcanic rocks with excess of Silica are:—

Quartz Trachyte, or Rhyolite, or Liparite, the "Lava of Granite," of crystals of Q. and F. (variety *Sanidine,*) in a paste of Q. and F.

Obsidian is a glassy form of the same; dark, lustrous, conchoidal.

Pitchstone, Perlite or Pearlstone, and **Pumice** are other glassy forms, the latter with cellular structure, the froth of Acidic lava.

The INTERMEDIATE group contains rocks with about 60 per cent. of Silica (55 to 66), and about 8 per cent. each of the Alkalies *Potash* and *Soda*, the Alkaline Earths, *Lime* and *Magnesia*, and the heavy metallic oxides.

The chief Plutonic rocks in it are:—

Syenite of **F** (1). and **H.**—a coarsely crystalline dark rock.

Mica Syenite or Minette, and Augite Syenite are rare varieties.

Elæolite Syenite has Nepheline in place of Felspar.

The "Porphyry" of the ancients is a purple porphyritic form of Syenite.

Diorite or **Greenstone** of **F** (2). and **H.** (and often M. or A.)
It is a common rock, and much like Syenite and Dolerite.

Diorite Porphyry was the Black Porphyry of the ancients.

Aphanite is the compact form of Diorite, and much resembles Basalt.

The chief Volcanic rocks of the Intermediate group are:—

Trachyte, a light grey lava, rough to the touch, with clear glassy crystals of F (1.) (variety Sanidine), usually small but often very large, in a glassy base of Felspar, &c.

Andesite, a Lava with neither Q. nor F (1.) (Sanidine), but of F (2.) H., and often A. and M., and named accordingly. It occurs largely in the Volcanoes of the Andes.

Porphyrite is an altered Andesite, abundant in the lavas of the Old Red Sandstone in Central Scotland, and in Germany.

Phonolite is a semi-crystalline rock, formed of plates of Nepheline and Sanidine F. It is lustrous grey, and clangs when struck.

B. BASIC GROUP, composed of poorly silicated Felspar, very rarely with any Quartz, but with excess of the bases Magnesia and Lime, and the oxides of Iron.

These are relatively heavy rocks (S.G. from 2.7 to 3) and easily fusible. They contain about 50 per cent. of Silica (45 to 55), but rarely any free; about 12 of Alumina, only 3½ of Potash and Soda, 18 of Magnesia and Lime, and 14 of the heavy oxides of Iron, &c., *e.g.*, Magnetite. Titanoferrite. These oxides of Iron are very prone to change into the Peroxide of Iron, or into this hydrated; such give red, brown and yellow tints to the rocks, while the altered Magnesian silicates constantly add green colourations.

The Felspar is rarely Orthoclase, but is usually Labradorite, F (5); and is often replaced in part or whole by Leucite, Nepheline, Nosean, &c. Augite is usually abundant, but Hornblende is rare. Olivine almost always occurs. Mica, if present at all, is Biotite, not Muscovite.

The chief Plutonic rocks of the Basic group are:—

Gabbro or Diallage rock, a heavy granite-like rock of grey or violet Labradorite, (F 5), Augite (usually the variety Diallage), with Magnetite, and often Iron Pyrites, Olivine, &c.

The Diallage is bronzy or pearly, and cleaves like Mica. Gabbro occurs in Skye and Mull, connected with volcanic outflows of early Tertiary age.

Hypersthene rock, Olivine Gabbro, Anorthite Gabbro, &c., are varieties.

Diabase of F (5), A, with Iron oxides, and also a green mineral *viridite*, (probably Chlorite, or else altered Augite or Olivine). A porphyritic variety, "Green Porphyry," from Italy, is much valued for ornamental purposes.

The chief Volcanic rocks of a Basic character are:—

Basalt, a very compact black rock, showing under the Microscope crystals of some Triclinic Felspar, usually F (5); Augite; also Olivine and much Magnetite and Titaniferous Iron, all embedded in a paste of glass or of crystallites.

Basalt occurs in lava streams, sheets, dykes, and veins, often in parallel columns, usually six-sided, which are perpendicular to the cooling surface. Some great districts covered by Basaltic sheets, are: 1. Idaho, Wyoming, &c., in the United States. 2. The Deccan plateau in India. 3. Abyssinia. 4. The Rhine, near Bonn. 5. The Western Isles of Scotland: Skye, Mull, Staffa (*Fingal's Cave*), also Antrim (with *Giant's Causeway*).

NOTE.—Some think these Basalt sheets were erupted, not from craters, but from great fissures, since wall-like dykes of Basalt are common; the Cleveland dyke extends for 100 miles, from near Whitby to near Carlisle.

Besides ordinary compact Basalt there are the following varieties:

Tachylyte or glassy Basalt, due to rapid cooling; abundant at Kilauea, *e.g.*, Pélé's Hair; elsewhere only known in thin bands.

Anamesite, with just visible crystals.

Dolerite with coarse crystals, much resembling Diorite and Syenite. (Hence the name from *doleros*, deceitful).

This includes most of the old "Greenstones" or "Traps," and is common around Edinburgh. It is often taken as the type of Basic lavas which are referred to as *Doleritic*, in contradistinction to the *Trachytic* or Acidic lavas.

Leucite Basalt (grey), without Felspar, common at Vesuvius.

Basaltic rocks are readily altered by the action of water and the weather; the Felspar changing by hydration to *Kaolin*, the black oxide of Iron to the brown or yellow hydrated peroxide, and any Olivine to *Serpentine* or *Chlorite*.

Melaphyre, a name loosely given to ancient altered Basalts.

It is red, green, or brown, and often amygdaloidal, as in "toadstone."

Wacké, a clayey rock, due to further decomposition of Basalts.

The Ultra-Basic group contains rocks, with only about 40 per cent. of Silica (35 to 45), but with 30 p.c. of Magnesia and Lime, and 20 of Iron oxides. Few contain any Felspar, but Olivine and Augite, with Chromite, Magnetite, &c., make up the mass, which is often altered into Serpentine.

Rocks of this group, though rare, are of interest owing to their composition, which approaches that of Meteorites, bodies of extra-terrestrial origin. The chief are Corsite with F (4), Peridotite, Picrite, Dunite, Lherzolite, &c.

The following terms relate to the structure of certain Igneous rocks, irrespective of their composition:—

Ashes—ash-like dust ejected by volcanoes with violence, and often carried by the wind enormous distances. They are formed from lava raised into blisters—well seen in scoriaceous lavas—by steam or other gases, and blown into the air, the fragments being ground to dust against one another during ejection.

Lapilli and Volcanic Blocks are coarser materials of similar origin.

Bombs are ejected masses of lava, porous or hollow within, but glassy without, and rounded, owing to rotation in the air.

Agglomerate is the coarse, unstratified debris in and around the craters of Volcanoes.

Lava is a general term for the molten rock of volcanoes, whether Rhyolitic, Trachytic, Andesitic, or Basaltic in composition.

The fluidal character is chiefly due to the large amount of water it encloses, which often gives a porous or scoriaceous structure to the solidified lava. The water may exist as such in the lava, though at a very high temperature.

Tuffs are consolidated ashes, often stratified and even fossiliferous, owing to deposition in water. Sometimes they are Volcanic mud, setting into a hard rock, as at Herculaneum.

Some Tuffs were probably lava streams suddenly cooled by water.

The Peperino found near Rome, and the Trass of the Eifel district are Tuffs of Tertiary date; the summit rocks of Snowdon are Tuffs of Lower Silurian age. Ancient Tuffs are abundant in central Scotland.

Amygdaloids are altered scoriaceous lavas, the cavities in which, due to expansion of steam and gases, have become lined or filled with various minerals, in almond-like masses (amygdules), deposited from solution in the water percolating the rock. The usual minerals are Quartz, Chalcedony (as in *Agate*), Opal; also Calcite, Zeolites, &c.

Porphyry is any rock having a porphyritic structure, *i.e*, with large crystals, usually of a Felspar, scattered through a compact base, usually felspathic.

The original Porphyry of the ancients was a Syenite with a purple base.

Black P. is a Diorite; Green P. a Diabase, Quartz P. a Felsite

NOTE.—Varied examples of Porphyries may be seen in Beach Pebbles, Kerbstones, &c. Porphyritic Granite is much used for decoration.

Table to show the relations of the chief Igneous Rocks.

I. Wholly crystalline, PLUTONIC or granitoid forms.

II. Semi-crystalline, compact, often Porphyritic forms (TRAPS)

III. More or less glassy, VOLCANIC forms, including Ashes and Tuffs

	I.	II.	III.
Felspar abundant, chiefly *Orthoclase* or its glassy variety, *Sanidine* (in III. only).			
With *Quartz*	**Granite** with *Mica*	Quartz Felsite Quartz Porphyry	Quartz Trachyte (Liparite or Rhyolite
No *Quartz*	**Syenite** with *Hornblende*	Felsite and Felstone Orthoclase Porphyry	**Trachyte** Pumice, Obsidian, &c
Felspar chiefly *Oligoclase*—free Silica or Quartz rare.			
With *Hornblende*	**Diorite**	Porphyrite	**Andesite**
With *Quartz* also	Quartz Diorite	Oligoclase Porphyry.	Dacite
Felspar chiefly *Labradorite*—Orthoclase and Quartz very rare.			
With *Augite* and *Magnetite*,	**Gabbro** if very coarse	Hypersthenite with *Hypersthene*	many Basalts.
Also *Olivine*, &c.	**Dolerite** if less coarse	**Basalt** if compact	Tachylyte if glassy
Chiefly of *Augite*, with little or no Felspar, and no Quartz.			
With *Nepheline*	Elæolite Syenite	Nepheline Phonolite, and Nepheline Basalt	
With *Leucite*	—	Leucite Phonolite and Leucite Basalt	

The above Igneous Rocks classed as to their **Place of Origin** are either:—1. Subaërial. 2. Subaqueous. 3. Subterranean. The two former classes include the products of Volcanoes erupted at the surface, either into the air, or into water.

The third class occurs in the following forms:—

(1) filling the chimney of a Volcano, forming a **Neck** or Plug;

(2) forced into lateral crevices as **Veins**; or into more or less vertical fissures, forming wall-like **Dykes**; or intruded into or between surrounding strata as **Intrusive Sheets**;

(3) solidifying at the "focus" or hearth of a Volcano, where a "Sub-volcanic Lava Lake" or reservoir of molten rock existed, from which the intruded and erupted lavas have been derived.

The Lavas, Ashes, and Tuffs of Subaërial or Subaqueous origin, *become* **Interbedded** *with the Sedimentary strata then forming, with which they are therefore Contemporaneous in age.*

Such can produce alteration (metamorphism) only of the beds beneath them, and may inject veins into these, but not into those above, which of course are formed later; both their surfaces, too, are often ropy and scoriaceous.

The Dykes, Veins, and Sheets of Subterranean origin are **Intrusive** in, and therefore *Subsequent in age* to, the strata surrounding them. [See diagram on p. IV.]

Such may cut across the strata, and inject veins into them *on all sides*, and alteration of the strata may occur wherever in contact with the intruded lava.

Intruded rocks are denser than Interbedded, and are rarely scoriaceous, though often glassy, owing to rapid cooling. It is by the Interbedded or the Intrusive character, that the relative age of an Igneous rock is known.

It is thus we learn that the Basalts of the Antrim plateau, *Giant's Causeway, &c.*, and of the Inner Hebrides, *Staffa, Skye, Mull, &c.*, are of early **Tertiary** (? Oligocene) Age, for they overlie Secondary rocks, and have leaf-beds of this age interstratified, and therefore contemporaneous The dykes which break through the older rocks of Antrim, are doubtless of the same age [See Section p. viii], as are also the still existing volcanic cones of Auvergne, the Eifel, Hungary, &c. In Western Europe, there was little volcanic action during Secondary Periods, though it was extensive in South Eastern Europe, and the Western States of America A small group of volcanic vents rose in Devonshire in early **Triassic** time.

In the **Permian** Period a group of small volcanoes rose in the West of Scotland, and to this period probably belong the many intrusive sheets and bosses of dark, heavy dolerite and basalt which both in England and Central Scotland pierce the Coal Measures; and probably also the older volcanic tuffs of *Arthur's Seat, &c.*

In the **Carboniferous** Period, prior to the Coal Measures, there were many small volcanoes opened in the lagoons and shallow seas of the Central valley of Scotland—Fife to Ayr. Still earlier in this period, in the same region, broad sheets of lava were emitted, and built up into plateaux, fragments of which exist in the terraced hills of Arran, Ayr, Stirling, Nithsdale and

Eskdale; *Arthur's Seat*, *Salisbury Crags*, and the *Castle Rock*, all in Edinburgh, and many other castle-crowned crags, being other relics. In Northern England the Tuffs and Lavas of the Cheviot region, the great Whin Sill and other Dykes, the Derbyshire "Toadstone," &c., are all of this age or the preceding one.

In the **Devonian** Period a series of grand Volcanoes lay along the line of the Grampians, the many granite masses of this range being probably old "Lava Lakes;" as the Sidlaw, Ochil and Pentland Hills and the terraced hills of Lorne, around Oban [See Map of the Devonian lakes in which the ashes accumulated, on p. XII.] are certainly the remains of the lava sheets and ashes, then erupted in such abundance, at intervals, from the Shetlands to the Cheviots, and reaching 6,000 feet in thickness.

In Devon and Cornwall, similar volcanoes also existed, *Dartmoor* and the Cornish granite bosses being their basal wrecks

In the **Lower Silurian** Period, in the Bala Beds, and before that, in the Llandeilo Beds, there are proofs of volcanic action having occurred on a truly grand scale in North Wales, and in the Lake district. *Snowdon*, *Cader Idris*, *Arenig*, *Skiddaw*, *&c*, have been carved by denudation from the vast piles of ashes and lavas then erupted, probably in great part beneath the Sea.

In the **Cambrian** Period submarine volcanoes in Wales discharged large quantities of fine ashes and lava over the sea bottom

NOTE.—It will be observed on a map, that the general direction of the bands of Volcanic action in Britain, in the Palæozoic Periods, was from N.E to S.W., while that of the Tertiary Volcanoes was from N to S, as is that of the existing, but decaying Volcanoes of the Mid-Atlantic series. Prof Geikie says:—"*No other area of equal size on the globe has preserved a fuller record* of ancient volcanic eruptions"

Prof. Ramsay said at Swansea:—"In nearly all geological ages, Volcanoes have played an important part, now in one region, now in another, from very early Palæozoic times down to the present day; but as far as my knowledge extends, at no period is there any sign of their having played a more important part than they do in the epoch in which we live."

THE DISTRIBUTION OF EXISTING VOLCANOES.

The number of great habitual Volcanic vents still in an active condition, is 300 to 350, but if we include mountains with all the features of Volcanoes, though not active during the historical period, the number is about 1,000. Far more exist, which, though formed of volcanic materials, have, owing to denudation, lost the external form of Volcanoes (Prof. Judd). Volcanoes occur chiefly in lines, and nearly all along three bands with their branches.

1.—East Pacific Band, from South Shetlands to Behring Strait (8,000 miles), and containing about 100 active volcanoes.

In the Andes of Chili (24 of which 13 active). *Aconcagua (ext.)*; of Peru, &c. (14—3) *Huallatiri*, *Sahama*; and of Equador and Columbia (18—10) *Chimborazo (ext.) Cotopaxi*, *Tolima*, *Antisana*, *Pichincha*

In Central America (29—18) *Agua*, *Coseguina*; In Mexico (6—4) *Orizaba*, *Popocatapetl*, *Jorullo*. In the Rocky Mountain group (10—1) mostly extinct, *Taylor*, *Fremont's Peak*, *Mounts Hood*, *Rainier*, *Brown*, *Fairweather*, *St. Elias*. In the Aleutian Islands (—34 active).

2.—West Pacific Band, from Behring Strait to South Victoria Land (10,000 miles), with about 150 active volcanoes.

In Kamtschatka (14) *Klinchev*, Kurile Isles (10) *Alaid;* Japan Isles (25), *Asama-yama, Fusi-yama, Aso-yama;* Loo Choo Isles, Formosa (3), Philippines, New Guinea (2), Fiji Islands, New Zealand (1-3), *Tongariro, White Island, Egmont (ext.,) Edgecumbe (ext.,)* South Victoria Land with *Erebus* and *Terror* (*ext.*)

These two bands form together the "Fiery Belt of the Pacific," which encloses many Volcanic Islands with 26 active volcanoes.

Sandwich Islands, Hawaii, &c (4), *Mauna Loa* and *Kilauea*, *Mauna Kea*. These Volcanoes are unsurpassed in height, bulk, and size of crater, since they rise out of a deep ocean. Society Islands, Easter Island, Galapagos Islands.

A great branch passes West from the middle of the West Pacific Band through the Sunda Isles, and contains 50 or more active Volcanoes.

Sumbawa Island, *Tomboro*, Celebes Island (11); Flores Island (6); Lombok Island and Bali Island, Java with 28 active. *Papandajang* and *Krakatoa*, both nearly destroyed in 1883. Sumatra (19-6) *Indrapura;* Coast of Burmah, *Barren Island*.

A very imperfect band is seen down the West side of the Indian Ocean and the Red Sea, the Volcanoes being mostly extinct. Comoro Islands, Bourbon Island, Mauritius Island, St. Paul Island, Kerguelen Land.

3.—Atlantic Band from Jan Meyen Island in the Arctic Ocean, and containing with its branches about 50 active Volcanoes.

Iceland (13) *Hekla, Skaptar Jokul, Snaefell Jokul*, Azores (6), *Pico;* Canary Islands (3) *Peak of Teneriffe*, C. Verde Islands, *Fuego*. Several submarine near the Equator. Ascension, St Helena, Tristan d' Acunha, Trinidad, all extinct.

A branch through the Lesser Antilles contains 6 now active.

Another branch includes the Cameroons, Fernando Po, St. Thomas, &c., all in the Gulf of Guinea.

An important branch runs through the Mediterranean, and includes :—

In Europe (6 active), on the mainland *Vesuvius, Monte Nuova* (extinct), both near Naples; and on islands *Stromboli, Vulcano, Etna, Graham's Island, Santorin Island*. The branch is continued East, chiefly by extinct volcanoes, through Asia Minor, *Ararat* (extinct), Persia, *Demavend*, and the Thian Shan Mountains.

Another branch, with no active vents, runs through North Spain, Auvergne, the Eifel, Bohemia, Hungary, the Crimea, and Caspian area.

In the two latter Mud Volcanoes (*Salses*) occur, and are still active.

A Volcano is "in eruption" when it ejects more or less explosively,

(*a*) **Gases**—chiefly Steam, Carbonic acid, Hydrogen, Nitrogen, Hydrochloric acid, Sulphurous acid, Marsh gas, &c.

(*b*) **Lava** or Molten rock; (*c*) **Solids** due to grinding of the rocky sides, the concussion of loose blocks, and the cooling of Lava streams or spray. Such form Volcanic dust or ashes, Lapilli, Bombs, &c.

The order of the phenomena of an eruption is usually:—

(1) Earthquakes. (2) Irregular ebb and flow of the Sea.

(3) Discharge of Steam, which condenses into clouds and rain.

(4) Explosion of Dust and Ashes, forming the so-called Smoke.

(5) Ejection of large blocks of stone and Volcanic bombs.

(6) Glowing of the Lava in the crater, forming apparent flames.

(7) Flow of the Lava from the crater, or from rents in the Cone.

(8) Gradual cession of the lava-flow, and return to rest.

The Earth's interior is still very hot, far hotter than molten iron.

"Probably at a depth of not more than 20 miles from the surface the temperature is as high as the melting point of any ordinary rock at the surface."—*Geikie.*

The proofs of such **Internal** or **Central Heat**, now or in the past, are:—

1.—The rise of temperature in descending mines, borings, &c., the average rate of rise being 1° F. for every 60 feet, after reaching the first line of uniform temperature, unaffected by surface changes, the depth of which varies with climate and rock material, and is about 100 feet in Britain; but it is improbable that this rate continues far.

The water from an artesian well at Grenelle, Paris, rises from 1,800 feet in depth at 83° F., the average surface temperature of the air and earth there being about 53°, which is nearly that of the first stratum of invariable temperature. One at Pesth, in Hungary, is the deepest yet made (3,120 feet in 1886), and yields 176,000 gallons daily, at 158° F.

2.—The existence of hot springs (*e.g.*, at Wiesbaden 156° F., Bath 120°) and of geysers in Iceland, New Zealand, and United States—in the Yellowstone region, Wyoming.

3.—The nature and high temperature of the products of volcanic eruptions, and the existence of intruded and massive crystalline rocks of presumably similar origin.

The structure and modes of occurrence of the Schistose rocks, and the contents of many lodes or veins of metallic ores, point to the action of great heat, or perhaps of hot water.

4.—The shape of the Earth—an oblate spheroid, such as would be taken by a rotating body, if not rigid as the Earth now is, but free to yield to centrifugal force, as it would have been when in whole or great part molten.

It is very probable that the rate of its rotation was formerly greater than now, the day being only 6¾ hours long about 57 millions of years ago; if so, the equatorial bulging was then much greater than at present (13 miles). It is probable that the day will at last be of the same length as the year, the rotation occupying as long as the revolution, as is the case now with the moon.

5.—The density of the Earth, which is about double the average density of the surface rocks, these being twice to thrice the weight of water.

Water being 1	Chalk is 2.49	The Earth's density was estimated
Granite is 2.65	Coal shale 2.59	by Maskelyne (plumb line) as 5.0
Basalt is 2.85	Sandstone 2.60	by Cavendish (torsion) as - 5.3
Gabbro is 2.95	Mica slate 2.69	by Airy (pendulum) - - - 6.6

The pressure of the rocks above, owing to gravitation, must compress the interior so as to render the mean density greater than 5 or 6, especially if, as is probable, heavy unoxidised metals exist largely there as an inner nucleus. It is hence assumed that the expanding force of heat counteracts to some extent the attractive force of gravity and so reduces the density to about 5.5.

The theories, or rather hypotheses, of the origin of this Central Heat and Volcanic heat, and of the Lava lakes which probably underlie active volcanoes, and perhaps extend in fissures beneath bands of volcanoes, are:—

1.—The **Chemical theory** of Davy—that the heat necessary to melt the rocks is due to the action of water on such metals as Potassium, Sodium, Calcium; and perhaps on such non-metals as Silicon, Boron; which he assumed to exist largely in the Earth's interior in the uncombined or *native* state.

NOTE.—Though compounds of these are abundant in the Earth's crust, none of them are known in nature in the native state.

2.—The **Mechanical theory**—that the liquid state of the rocks locally is due to friction of moving parts, either of the rocks on opposite sides of a fracture or *fault*; or of the particles of the crust itself in becoming folded or crumpled owing to contraction as it cools.

It may also be due to partial relief of the enormous pressure due to gravitation or weight of the overlying masses, as well as to contraction in cooling, for since rocks expand in becoming liquid, pressure may prevent melting, and relief of pressure permit it when the temperature is sufficiently high.

3.—The **Original heat theory**—that the interior of the Earth below a few miles has remained fluid from the first, either—(1) throughout below a thin crust, or (2) in a certain zone between a solid central mass or *nucleus* and a solid crust, or (3) in certain detached or slightly connected areas—the assumed Lava lakes.

"The hypothesis of the Original Heat of the Globe, falling in with the 'Nebular Theory,' is useful in accounting for its shape, its specific gravity, its existing heat, the universality of volcanic action, the uniform characters of volcanic products in all parts of the globe and at all times, and for the origin, form, and structure of continental areas of land as stable portions of the contracting crust of the cooling mass, the cracks and boundary-lines allowing the outburst of molten matter from the interior."—*Morris and Jones.*

The Nebular theory of Laplace referred to supposes the Earth to have once been an intensely heated rotating mass of gas, or incandescent vapour, a fragment of a far greater cloud or *nebula*, of which the other planets are other detached parts, and the sun itself the last remnant. By loss of heat into space these have acquired their present conditions, for the most part solid or semi-solid, or like the sun, still remain gaseous.

Different estimates of the thickness of this assumed crust are :—

Arago, 22 miles ; Humboldt, 24 ; Lyell, 34 ; Cordier, 65 ; Morris, 300 ; Hopkins, [illegible]000 miles, at least ; and Sir W. Thomson thinks there must be a rigid crust at least 2,000 miles thick out of a possible 4,000 miles to prevent the Earth's crust being affected by the tidal motions of the molten interior, as well as by nutation and precession

The Sedimentary or Derivative Rocks, known also as Clastic and as Stratified Rocks.

These are derived directly or indirectly from the crystalline rocks. The Felspars and allied minerals in these, slowly acted on by water containing carbonic acid, lose their Potash, Soda, or Lime ; and the Silicate of Alumina left, uniting with water, forms *Kaolin*, the basis of all clays. It consists of Silica 46, Alumina 40, water 14 per cent. The quartz crystals and blebs set free by this disintegration of granite and other quartziferous rocks become Sand, at first angular, but becoming rounded by the action of streams, currents, or winds. It is thus are derived most clays and sands.

NOTE.—For the Volcanic rocks of this class - Ashes, Tufts, Breccia, &c (see p. 34.)

These rocks are best classed as to their mode of accumulation (see p. 30, 48).

1. FRAGMENTAL or CLASTIC due to mechanical action merely.

As to material, these are chiefly *Arenaceous* (sandy)
or *Argillaceous* (clayey).

Cliff-debris—coarse, angular rubbish, loosened by the weather from bare faces of rock. *Screes* and *Taluses* are banks of such debris at the base of cliffs. *Moraines* and *Perched Blocks* are of similar origin, but transported by ice. *Soil* and *Subsoil* are similarly derived from the weathering of the surface rocks, assisted by plants and animals.

Breccia—composed of angular fragments cemented or compressed into solid rock.

Bone Breccia, found in some caves, consists of bones of animals once living there, or of their prey, cemented and encrusted by stalagmitic carbonate of lime

Gravel, Pebbles, Shingle—loose, rounded, water-worn fragments of flint, quartzite, jasper, porphyry, granite, or other hard rock. Ordinary gravel has been formed by rivers.

Conglomerate—of similar rounded materials consolidated into solid rock. It is popularly known as Pudding stone.

Sand—finer fragments, usually of quartz, but sometimes of limestone ; well rounded in desert sand ; subangular in river and sea-sand ; angular in glacier sand.

***Arkose* is a conglomeratic sand consisting of disintegrated granite.**

Sandstone—consolidated sand, chiefly quartzose, but often also micaceous, as in most paving-stones.

Grit is formed of coarse or sharp quartz grains; it is often used for millstones.

Flagstone is a thin-bedded sandstone, much used for paving.

Freestone is thick-bedded and without tendency to split in any one direction.

Greywacke is a very hard, dark, impure sandstone with much felspar.

Grey-wethers, or Sarsen-stones, are scattered blocks of hard sandstone (of Eocene Age) resting on chalk, *e.g.*, on Salisbury Plain.

Greensand contains green grains of Glauconite. [See p. 28-45.]

Red Sands owe their colour to a coating of Peroxide of Iron [See p. 28.]

NOTE.—The consolidation of loose materials into firm rock may be due to—

(1) *Pressure*—of overlying water, or of overlying rocks, or of disturbances such as folding and faulting of strata.

(2) *Chemical Changes*, partial solution and re-deposition, &c.

(3) *Heat*—either dry heat or moist heat.

(4) *Cementing-matter*, especially Carbonate of Lime, Silica, Peroxide of Iron, Clay.

Clay—a very fine-grained rock, essentially of hydrated Silicate of Alumina; white when pure, but oftener coloured green, brown, blue, red, purple, by various compounds of Iron, or black by organic matter. It is plastic when wet, but crumbles and adheres to the tongue when dry, and has a peculiar odour.

Kaolin, or China Clay, is the pure white variety, so valuable for porcelain.

Pipe-clay is nearly pure, and free from iron. At Bovey, in Devon, Hampshire, &c.

Fire-clay is free from alkalies and iron, so will not fuse when strongly heated. The underclay beneath coal seams is usually of this nature. [p. 2.]

Brick-clay is any sandy clay (loam) from which bricks can be made. The Brick Earth of London and the Midlands is mostly of Post-Tertiary Age.

Fuller's Earth is a non-plastic clay with much iron, lime, and soda.

Boulder-clay, or **Till,** is a stiff unstratified clay full of angular stones often ice-scratched, and abundant in the valleys of Scotland, &c. [See p. 5.]

Loess is a pale, firm clay with much lime and sand, of doubtful origin, but unstratified, and with many land shells and land plants and animals. It resembles the soil of Steppes, and occurs in the larger river valleys of Central Europe, in China, &c., but not in Britain.

Mudstone, or *Clay-rock*, is hard and compact, and without tendency to split.

Marlstone (of Middle Lias age) is nearly similar, but with calcareous matter.

Marl is clay or shale with much lime, and easily crumbling if dry.

N.B.—The New Red Marl (of Keuper age) is a true clay, without lime, but not plastic, and not effervescing with acids, as marl does.

Shale—hardened clay, splitting into thin layers (laminæ).

This fissile structure is found in most of the old clays, if unweathered

Slate—of similar material, but altered since deposition by lateral pressure.

A Shale is *laminated*, splitting along and parallel to the planes of bedding.
A Slate is *cleaved*, splitting in parallel planes other than those of bedding.
A Schist is *foliated*, splitting into irregular layers of different minerals.
The two latter are metamorphic or altered rocks. [See p. 47.]

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2. Rocks of CHEMICAL ORIGIN formed by precipitation from solution in water, owing usually to chemical changes.

As to material these may be *Calcareous*, *Magnesian*, *Saline*, *Siliceous*, *Ferruginous*, *&c.*

Limestones of this class are Stalactite, Stalagmite, Travertine, Calc Tufa, &c., deposited by calcareous springs and streams from solution of Carbonate of Lime in water containing free carbonic acid, owing to the escape of this gas on exposure to air.

Oolite (roestone) and *Pisolite* (peastone) are granular forms, the rounded grains being not waterworn, but concretionary; of concentric shells of calcite deposited around some nucleus.

Freestone—is the variety most used in building. [See page opposite.]
Cornstone—a sandy form, of coarse concretionary structure, often embedded in marls or shales of Palæozoic age.
Cornbrash a clayey variety, rubbly or brashy (of Lower Oolite age).
These both crumble readily on exposure, and make good soils for corn
Hydraulic Limestone—a clayey variety which, when burnt, will harden under water, and so has been much used as a cement.

Dolomite, Magnesian Limestone—a mixture of the Carbonates of Lime and Magnesia, up to 45 per cent. of the latter. [See p. 27, No. 8, and p. 47.]

It may be compact, crystalline, cavernous, oolitic, or even coarsely pisolitic in structure. It is harder than limestone, and only slightly effervesces with acid. It forms huge mountains (of Triassic age) in the Eastern Alps.

Gypsum—a soft rock consisting of hydrated Sulphate of Lime.

It may be crystalline, or fibrous, or veined (See p. 27, No. 9), and occurs in beds or veins, usually with layers of red clay and rock-salt. The beds were formed in lakes or lagoons with no outlet, save by evaporation, the veins by alteration of limestone by the action of soluble sulphates, or of sulphurous vapours. The same occurs without combined water *(Anhydrite)*.

Rock Salt—occurs in thick cakes of small area. [See p. 21.]

In Cheshire it is 100 feet thick; in Galicia 4,600 feet, near Berlin still more. It is now forming in many salt lakes lying in regions of inland drainage.

Ironstone—The various ores of Iron (see p. 28) have mostly been precipitated from solution in lakes, marshes, or in fissures and cavities of rocks.

The nodules of Siderite, often septarian, have been deposited round an organic centre, and are usually embedded in clay, interstratified with coal and shales, and are known as Clay Ironstone, or Black-band.

Geyserite or Siliceous Sinter—deposited from the hot water of geysers and other hot springs, forms basins, terraces, and mounds in New Zealand, Wyoming, and Iceland.

Vein Quartz may be of similar origin, deposited in fissures from hot water. It often forms broad dyke-like reefs, in which Gold and other metals frequently occur. [p. 20.]

Flint occurs as nodules of silica, probably deposited from solution around some organism, *e.g.*, a sponge, an Echinus, a shell-fish.

Chert is an impure variety of various colours, occurring in other strata than chalk, especially in Sands and Sandy clays, and in many Limestones.

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3. Rocks of ORGANIC ORIGIN—formed of the remains of animals or of plants, and usually accumulated where these lived.

They are either built up directly by these or formed of their fragments.

As to material, they are *Calcareous*, *Siliceous*, *Phosphatic*, *Carbonaceous or Ferruginous*.

Limestones are Calcareous rocks, and, as a rule, are of animal origin, though usually this is not evident owing to an internal crystalline re-arrangement. The source may be—

(1) *Molluscan and Crustacean Shells*, as in the shell marl and freshwater limestones of lakes (p. 2).
(2) *Polyzoans;* (3) *Crinoids* or Encrinites, fixed Echinoderms.
(4) *Corals*, especially reef-building kinds.
(5) *Foraminiferal shells*, especially (? *Eozoon* p. 14), *Fusulina*, *Orbulina*, *Globigerina*, *Nummulites* (p. 6), *Miliolites*.

Other Limestones are formed largely of certain low plants (Algæ), which encrust themselves with Carbonate of Lime, *e.g.*, *Chara*, *Corallina*, *Melobesia*. The supposed joints of the latter, known as "coccoliths," and its spore-cases known as "coccospheres," form an appreciable part of chalk as well as of the Atlantic ooze, the larger part of these deposits being fine amorphous particles of Lime, with here and there *Globigerina* and allied shells, broken or entire.

Chalk—a white, earthy variety, very free from sand, pebbles, &c., but containing nodules of Iron-pyrites and of Flint, shells and spines of Echinoderms, spicules of sponges, and shells of Foraminifera, the latter forming about half the bulk.

Shell Sand—a shore deposit of much broken shells, often cemented together, *e.g.*, Red Crag.

Encrinital Marble—a clear-sea deposit of the broken stems and arms of Crinoids, usually crystalline, and mingled with other calcareous fragments. It is often used for mantelpieces.

Shell Marble (of the Wealden and Purbeck beds) is a freshwater deposit of shells of *Paludina* with *Limnæa*, &c. [See p. 2.]

Coral-rock—formed of the stony skeletons of certain polyps living in warm and shallow water, *e.g.*, Wenlock L. Coralline Oolite, Carboniferous L. (in great part). Devonian L. of Plymouth, Torquay, &c.

The chief **Siliceous Rocks** of organic origin are:—

Diatom-earth (Infusorial earth) formed of the cases of very minute plants (Algæ), common in both salt and fresh water.

A diatom-ooze is now forming over wide areas in cold seas, and it often occurs under peat bogs. Thick deposits are worked at Richmond, Virginia; and at Bilin, Bohemia, &c., as "Tripoli-powder," "Mountain-meal," "Dynamite-earth," or *Kiesel-guhr*.

Radiolarian-ooze, formed in deep seas of the minute shells of animals allied to the Foraminifera, *e.g.*, Barbadoes earth,

Glauconite-ooze consists of casts in green Glauconite (see p. 28) of the chambers of Foraminiferal shells. It forms layers in the Greensand formations, and may be dredged in the Pacific, off Australia.

Flints consist largely of organic particles—diatoms, spicules of Sponges, &c.

Phosphatic deposits (Phosphate of Lime) are formed chiefly from the bones and droppings of vertebrate animals—fishes, reptiles, birds, cetacean mammals, and but rarely of shells.

The chief are *Bone Beds*, *e.g.*, those of the Ludlow, Coal Measures, and Rhætic Beds; *Guano* found on rocky islands and coasts in very dry regions; *Coprolites* (see p. 22) occurring chiefly as nodules, and now largely worked for manuring land, after artificial change into Superphosphate of Lime.

Carbonaceous deposits are of vast importance to man for fuel, light, and motive power [see pages 18–20, 28].

They may be *solid* as Coal, *viscid* as Mineral pitch and Asphalt, *liquid* as Petroleum and Naphtha, or may evolve inflammable *gases*, fire-damp, &c. They consist chiefly of Carbon and Hydrogen, derived in most cases from plants, chiefly non-flowering kinds (*Cryptogams*)—mosses, club mosses, ferns. The mineralisation has been a very slow process, water (H_2O), marsh gas (CH_4), and carbonic acid gas (CO_2) being evolved, and in some cases bitumen being formed by a process of distillation.

Coal is without doubt of vegetable origin, as proved thus:—

(1) It consists of the same elements as chiefly compose plants, and its ash is much like that of burnt wood.

(2) It often shows the cellular structure found in all plants.

This is especially well seen in the thin silky flakes, "mother of coal."

(3) The undoubted roots, stems, leaves and fruits of plants, or impressions of these, are found in the Coal, or in the shales, sandstones, &c., associated with the coal seams.

(4) Beneath each bed of Coal is usually seen the Underclay, with many roots in position as they grew.

Some coals are made up chiefly of the stems, roots, and foliage; others almost entirely of the spore-cases and spores of large tree-like plants allied to our existing Club-mosses (*Lycopodium*), Horse-tails (*Equisetum*) and Ferns; partly also of Pines and Cycads (in Secondary strata.) Some Lignites largely consist of the remains of flowering plants (*Phanerogams.*)

The following shows the differences between the chief rocks allied to coal, the numbers referring to the per-centage amounts of Carbon in each, which increases as the mineralisation is more complete, owing to the gradual loss of other elements.

Peat (60)—formed chiefly of Bog-moss *(Sphagnum).*
Lignite (66), Brown Coal—mostly of Tertiary age, epecially Miocene
Cannel (66), Jet is a pure variety—probably of drifted plants.
Common Coal (75–80) including Caking Coal, and Cherry Coal.
Steam Coal (80), Splint or Hard Coal—used for Steam Engines.
Anthracite (90–95), Stone Coal—is hard, brittle and lustrous.

It ignites with difficulty, but gives great heat and little smoke.

In South Wales the last three kinds are found successively in travelling from East to West, the mineralisation being most complete in Pembrokeshire.

Graphite (98–100), Black-lead, is probably of Organic origin.

Petroleum or Rock oil, and similar Bituminous deposits.

This is rare in Britain (Derbyshire, Torbane Hill, &c.), but abundant in Hungary, Galicia, Crimea, the Caspian region, Burmah, and still more so in Pennsylvania and Canada, occurring there in porous sandstone of Silurian and Devonian age, while in Europe-Asia the chief deposits are of Eocene and Miocene age.

The chief **Ferruginous deposit** of organic origin is Bog Iron *ore, or Lake ore, still forming in the Swedish lakes.*

A small confervoid Alga (Gallionella ferruginea), and certain Diatoms appear to aid largely in the precipitation of the Iron oxide, which in its turn is dissolved from rocks by the organic acids set free by decomposing plants in marshes.

"The existence of beds of Iron ore affords strong presumption of the existence of contemporaneous organic life, by which the iron was dissolved and precipitated."—*Geikie.*

THE METAMORPHIC OR ALTERED ROCKS.

A Metamorphosed rock is one, whether at first crystalline or clastic, which has suffered a mineralogical re-arrangement whereby a new structure has been produced. The alteration may be either—

(*a*) A mere re-arrangement of its particles —Clay slate
(*b*) A crystallization of its constitutents —Marble; Schists
(*c*) The addition of new substances from solution in water percolating through the rock, and thence the production of new crystalline minerals —many Dolomites

The changes produced depend, both in nature and extent, on—

(1) The nature of the original rock material.
(2) Heat—which may be great enough to produce fusion.
(3) Pressure—due to the weight of overlying strata or of water, or to slow movements of the Earth's crust, producing a *shearing action*, and resulting in a cleaved or a schistose structure.
(4) Water and mineral solutions, especially if *acid* or *alkaline.*

Just as the crystalline structure of rocks is undone as the surface is approached, so it is produced as a rock is carried down to great depths, or is exposed to intense pressure, or to the heat of igneous eruptions or injections, if at some depth. Thus in the former case flecks of Kaolin appear in the Felspars, in the latter case flecks of Mica, Talc, Felspar, &c., may appear in clays until a schist, gneiss, or even possibly granite is produced.

The chief rocks of this class are FOLIATED or SCHISTOSE.

A **Schist** consists of alternating layers or *folia* of certain minerals *in crystals*, and splitting along these layers.

The folia are often wavy or puckered, and usually welded together. They are not continuous, flat, parallel layers, but thin out, die away, then reappear. Now and then the foliated structure gradually disappears, and in Quartzite is rarely apparent.

Almost any rock may, by great crushing and shearing movements, be converted into a Schist, *e.g.*, Granite into Gneiss; Sandstone into Quartzite; Clays into Mica-schist.

Volcanic ashes and tuffs, and some Lavas, are sometimes foliated.

Talc-schist consists of scaly Talc, with or without Quartz, &c.

Chlorite-schist of green Chlorite and Quartz, and often Felspar, &c. It is abundant in Scotland, the Alps, &c.

Hornblende-schist chiefly of dark green or black Hornblende.

Actinolite-schist consists chiefly of a bright green variety of Hornblende. Hornblende rock is a massive form, not schistose, and abundant locally.

Mica-schist of Quartz and Mica, varying much in texture.

The Mica is usually Muscovite, or, in the lustrous schists, a Hydrous Mica (p. 27). *Garnets are often present, and even abundant.*

This rock often covers great areas owing to "regional metamorphism," and also forms bands around granite masses owing to "contact metamorphism."

Gneiss consists of Felspar, Quartz and Mica, in irregular folia.

The Felspar is in crystalline grains, chiefly Orthoclase, often also Oligoclase. Hornblende and Talc and even Graphite may also occur, replacing the Mica.

Protogine, Granulite, and **Halleflinta** are usually foliated (p. 31.)

The above foliated rocks are probably in most cases highly altered stratified rocks, but their original nature, and in most cases their geological age, can but rarely be certainly ascertained. The Schists of the Scottish Highlands, long thought to be of Lower Silurian age, are now known to be of Pre-Cambrian age, possibly Laurentian.

Granite is probably metamorphic in such cases as when unaltered rocks are seen to pass gradually into Mica Schist, this into Gneiss, and this, by absence of foliation, into Granite.

Quartzite is a very hard, compact rock—an altered Sandstone.

It is rarely schistose, but often shows false-bedding, and even contains fossils.

Crystalline or **Saccharoid Limestone,** Statuary Marble, is a pure limestone, *e.g.*, Chalk, altered by heat under pressure.

Dolomite is, in some cases, a Limestone altered by the partial substitution of Magnesium for Calcium (see p. 27–8).

Serpentine rock, Green Marble, &c., is sometimes an altered Dolomite, but oftener altered Olivine, Augite, &c. (p. 27).

Graphite is possibly altered Anthracite, as this is certainly Coal altered by pressure, heat, and loss of gases.

Clay Slate is clay altered by pressure, so as to cleave very readily.

It consists of granular Kaolin, and often contains fossils distorted by pressure and the shearing action which have produced the very perfect cleavage. This cleavage is quite independent of the original layers of stratification, and usually crosses these at a high angle, but may coincide with them here and there.

In some cases Chiastolite, Mica, and other minerals appear in the slate, which may pass into a Schist, especially where the Clay Slate abuts on Igneous rocks.

Table to show the relations of the chief AQUEOUS Rocks.

UNALTERED.	*Siliceous.*		*Calcareous.*
Mechanically-formed rocks.	Gravels, Pebbles, Sands, Sand-rock, Sandstones, Grits, Conglomerates and Breccias (most).	Mud, Silt, Clay, Marl, Shale. Slate-clay.	L. - Limestone, Shell sand, Coral sand.
Chemically-formed rocks.	Sinter (Geyserite). Flint (amorphous). Chert (granular)	Kaolin, Septaria, Black band.	Travertine. Calcareous Concretions.
Organically-formed rocks.	Tripoli-earth. Diatom ooze. Radiolarian ooze.	"Red Clays" of deep seas (possibly).	Oolitic L. Pisolitic L. Coral reef L. Chalk, Ooze.

NOTE.—Coal, Coprolite, Bog Iron-ore, &c., are also organically derived rocks.

METAMORPHIC.	*Siliceous.*	*Argillaceous.*	*Calcareous.*
Slightly altered.	Quartzite or Quartz rock.	Lydian stone, Jasper (some).	Compact L. Dolomites.
Slaty rocks.		Clay Slate, Mica Slate, &c.	
Schistose rocks.	Quartz Schist.	Mica Schist, Talc ,, Chlorite ,, Hornblde ,,	Calc Schiefer.
Gneissose rocks.	Granulite, Greissen, Graphic Granite.	Gneiss. Garnet rock, Schorl rock.	Crystalline L. or Marble. Serpentine L.

INTERNAL CAUSES OF CHANGE.

The deep-seated causes of change are probably due to the earth's internal heat. [For facts and theories as to this see pp. 39, 40.] This once must have been far greater than it now is, and it far more easily reached the surface when the crust was thin, and so was lost by radiation into space.

Besides Metamorphism, or mineral and chemical alterations in rocks, there are four other kinds of phenomena under this head—

1.—Volcanic action —described on pp. 36—39.

2.—Earthquakes or sudden vibratory movements.

3.—Slow movements of elevation or of depression.

4.—The folding, crumpling, and faulting of strata.
(This probably accompanies slow elevation and depression.)

2.—**Earthquakes** are earth waves, due to a sudden shock, either

(*a*) The cracking of rocks under strain, with production of faults, the throw of which may be very slight;

(*b*) The collapse of the roofs of underground caverns;

(*c*) The sudden generation of steam or other volcanic vapours owing to water getting access to heated rock.

(*d*) The sudden condensation of steam under pressure, owing to access of water through fissures.

The small tremors constantly recorded by suitable instruments (*seismographs*) may be due to changes of surface temperature or pressure, to tides, &c

The wave travels with great velocity in all directions from the point of origin or *focus* The depth of this rarely exceeds 30 miles measured on the *Seismic vertical*, where the shock is uplifting, not overturning The *angle of emergence* of the wave decreases as we recede from this line, and so does the force of the impulse, though the overturning effect increases A line joining points on the surface where the angle of emergence is the same is a *co-seismic line*, the points being *co seismic points* Knowing the angle at which the vibration reaches the surface at any two or more distant points, the place and depth of origin can be calculated

The permanent changes wrought by earthquakes are but small, though the havoc may be great, especially on low lands bordering on the sea, owing to the great waves of water which roll in. These often flow far inland bearing even large ships, and may inundate and destroy coast towns

Earthquakes may cause landslips, or may open fissures in the ground which may deflect streams, so altering the drainage, the fissures being sometimes enlarged by the streams into ravines; but this origin of river gorges is rare.

Permanent changes of level often accompany earthquakes; either *elevation*, as in Chili in 1822, when 100,000 square miles were lifted from two to seven feet; and in 1835, when a greater area was affected; or *depression*, as in Cutch in 1819, when 2,000 square miles of dry land became a salt lagoon—the Runn of Cutch.

3.—**Slow Movements of Elevation** are in progress in most regions of active volcanoes, and along the Arctic shores of Europe, Asia and America, extending to Sweden and North and West Britain.

4.—**The Folding and Faulting of Strata.**—Most rocks of Aqueous origin have been deposited in approximately horizontal layers or *strata*, but subsequent movements of elevation or of subsidence, sudden or gradual, have usually and often greatly altered this arrangement, the strata inclining in different directions or to different amounts in different places. The only explanation of this is that *the rocks have been folded into a series of troughs and arches, or thrown into domes or basins.* Superadded to this there often occurs finer folding or *contortion*, and even inversion, accompanied usually by fracturing and crushing of the strata.

"The crust of the earth has been folded and crumpled on the most colossal scale, some parts having been pushed for miles away from their original position; it has been rent by profound fissures, on each side of which the rocks have been displaced for many thousand feet; and it has been so broken, crushed, and sheared, that its component rocks have in some places assumed a structure entirely different from what they originally possessed."—*Geikie.*

Dip of a bed is its inclination to the horizon, and is measured as to its direction by the *compass*, as to its angle with the horizon by the *clinometer*, expressed in degrees.

The bed may be said *to rise* in the opposite direction to its dip.

Outcrop of a bed, or of a formation, is the line or band on the ground where it is exposed at the surface.

Most of the colours on a geological map refer to the outcrop of particular formations or systems, as explained in the index of colours.

Strike, *i.e.*, *Stretch*, of a bed is the general direction of its outcrop, with which it corresponds when the ground is horizontal or when the strata are vertical. At any given spot it is *a horizontal line at right angles to the direction of dip.*

Thus, if beds dip to S. or N., their strike is E. and W. Knowing the angle of dip and breadth of outcrop of a bed or series of beds, measured horizontally and across the strike, its true thickness may be easily calculated.

Where the folding has been on a large scale, the following terms are used:—[See sketches on p. I. and VI. to IX.]

Anticlinal, or Saddleback, when the strata dip in opposite directions *from a line* or axis; *e.g.* the Weald, the Pennine and Mendip Hills, the Isle of Wight (southern half).

Synclinal when strata dip *towards a line* or axis; Snowdon.

Periclinal, quaquaversal or domed, strata dip away in all directions *from a central point*: *e.g.*, many Inliers.

Centroclinal strata or **Basin** when the beds dip in all directions *towards a central point*, *e.g.*, the London and Hampshire basins, and most coal-fields.

Artesian wells are only possible in or over such a curve, and where porous strata, as chalk, sand, &c., exposed at the margin of the basin, are overlaid and underlaid by clay or other non-porous strata.

Monoclinal when the strata of a district dip in one main direction but at different angles; and especially where there is an abrupt change of dip, then a return to the previous dip, as in the Isle of Wight (northern half.)

Isoclinal strata are such as have been so folded and inverted that the reduplicated members appear to dip regularly in one direction, as in the Alps and Jura, and most great mountain ranges.

Inverted strata are such as have been so folded that older strata overlie newer ones; as in the Jura (p. I.)

Where the scale of the folding is small, the term **Contorted** is used for highly crumpled strata, each bend being a *flexure*. This is usually accompanied by structural or mineral alterations, *i.e.*, metamorphism (p. 46).

Faults or dislocations (hitches, heaves and troubles of miners) are cracks or *fractures of strata, accompanied by displacement*, the broken ends of the strata on the "upthrow side" being raised above, or those on the "down-throw side" depressed below the previous level. (See sketches on p. II. for Simple, Trough, Dike and Step Faults.)

The fault inclines (*hades or dips*) to the downthrow side, but in rare cases to the upthrow side, producing a Reversed Fault Vertical Faults with no hade also occur. The *strike* of a fault is the general direction it takes on the surface. The *throw* of a fault is the extent of displacement measured vertically. The smooth or grooved walls of a Fault are called *slickensides*. A great fault crosses Scotland from near Stonehaven to Loch Lomond, with a throw of several thousand feet, separating the ancient crystalline rocks of the Highlands from the Old Red Sandstone rocks of the Lowlands, and throwing the latter strata on end for a breadth of two miles. Another crosses from near Dunbar to Ayr, with a throw in places of 15,000 feet.

Effects of faults.—(1.) *Dip faults*, which of course run across the strike and out-crops of strata, produce a lateral shift, as well seen on geological maps.

rike-faults are less easy to detect, but alter the width of out-crop of a bed, and may quite carry it out of sight.

(3.) Waterfalls may result, either immediately or later.

(4.) A line of Springs, often with hot or mineral waters, is a very common result of a fault, since this offers an easy passage to the surface for underground waters.

(5.) A surface ridge is produced, but save in very rare cases (*e.g.*, the Pennine Fault in the Eden Valley, West of Cross Fell), it is soon destroyed by denudation, in which case the amount of throw gives a measure of the minimum denudation.

In the Grand Canon District of Utah, where atmospheric denudation is very small, every fault produces a cliff or steep slope, easily however distinguishable from cliffs of erosion.

(6.) In mining works faults often entail enormous labour and cost in searching for the continuation of a stratum or a lode cut off by a fault.

(7.) Faults often become converted into Lodes or Mineral Veins by deposition on their sides of ores and spars.

EXTERNAL CAUSES OF CHANGE.

Such are due to the action of the sun, whose heat raises water as vapour to fall as rain or snow, and also sets up air currents (winds) and ocean

Denudation is the term applied to the process by which the surface of the ground is broken up, and its ruins carried away so as to lay bare *(L. denudo)* new surfaces. The effects on the earth's surface of the various **Agents of Denudation** are in part *destructive*, in part *transportive*, and in part actually *constructive*. These agents are especially 1. **Wind**: 2. **Frost and Ice**: 3. **Plants and Animals**: 4. **Rain**: 5. **Running Water**: 6. **The Sea.** The action of the latter is said to be *marine*, that of the others *subaërial*, that of the wind especially *Æolian*.

TABLE TO SHOW THE RESULTS OF DENUDATION.

DIRECT AND INDIRECT.

Destructive Effects.	Constructive and Scenic Effects.
A. ATMOSPHERIC agencies which produce "weathering" of rocks	The formation —of Soils & Sub-soils;
1. Motion of the air (winds), and of blown sand.	—of Rain-wash, Brick-earth, Loess;
2. Chemical action of gases of air.	—of Screes and Taluses below cliffs;
3. Changes of temperature when rapid and considerable (as heat expands and cold contracts).	—of Sand-dunes on coasts and inland; —of Escarpments and cliffs (in part), —of Earth-pillars, as in the Tyrol;
4. Expansion of water in freezing in the pores and cracks of rocks.	—of Alpine peaks and needle-like pinnacles (*aiguilles*), and of our English "tors,"
5. Action of rain — *mechanically* in loosening rocks, *chemically* in dissolving them.	—of Landslips, as in the Undercliff, Isle of Wight; Axmouth, (in 1839) the Rossberg, near Lucerne (1806)
B. ORGANIC agencies.	The formation of protective turf;
1. Boring by molluscs under water.	—of Peat, Lignite, and Coal;
2. Boring by earthworms in the soil.	—of Coral-reefs, Foraminiferal ooze, Chalk, and other Limestones;
3. Burrowing by moles, rabbits, &c.	—of Siliceous deposits in the sea, *e.g.* Diatom ooze, Sponges, and nodules of Flint and Chert;
4. Building of dams by beavers.	
5. Loosening of rocks by roots of plants.	—of Guano, Coprolites (droppings, bones, teeth, &c.), and Bog-iron ore;
6. Chemical action of Carbonic acid given off by the decay of plants.	
7. Increase of rainfall owing to trees.	Protection of loose materials by the intertwining roots and stems of plants.
8. Human agency, for man is "the great disturber of nature,"	

C. Action of RUNNING WATER Rivers and torrents (including underground waters) act 1. *Chemically*—by dissolving rock-salt, gypsum, &c., and (owing to the carbonic acid always present in such water) also limestones, thus rendering the water "hard." Such carbonated water also decomposes the felspars of the crystalline rocks (see page 41). The Thames carries past London about a ton per minute of mineral matter in solution.	The formation of certain Lakes, *e.g.*, the Cheshire Meres, the Shannon Lakes, &c. —and of certain gorges (in part), *e.g.*, El Ghor of the Jordan. —and most limestone caverns. The deposition of Stalactite on roofs, —and Stalagmite on floors of caverns, and of Travertine (or Calcareous Tufa) on the banks of springs and streams, —and of Kaolin from felspars, &c.
2. *Mechanically* In deepening their channels and removing the detritus due to weathering, thus widening as well as deepening valleys, and lowering the general level of a country. NOTE.—It is calculated that the average lowering by denudation amounts to about a foot in 6,000 years. The Rhone carries to sea yearly about 40 million tons of sediment, the Danube about 68 millions; the Mississipi 363 millions of tons, of which 50 millions are coarse matters pushed along the bottom, the rest finer matters in suspension	The formation of Alluvial deposits, gravel, &c., on level tracts (the *flood plain* of a river), and the subsequent production of River-terraces of gravel, &c., owing to deepening of the channel. —of Deltas, at the mouths of rivers, unless when prevented by (1) Strong tides or currents (2) Too great velocity of stream (3) Passage through a lake in the lower part of its course of Pot-holes and Swallow holes in the bed of a stream —of Waterfalls where a stream crosses the outcrop of a harder stratum to that of a softer. —of Canons, Gorges, and Ravines.
D. GLACIAL agencies. 1. Avalanches of snow which may sweep down rocks, trees, &c., block up valleys, and cause temporary lakes and destructive floods. 2. Glaciers or Ice-streams formed of the granular snow (*névé*) found in mountain valleys above the snow-line. By pressure, and by melting by day, and re-freezing by night, a stratified structure is produced. The motion of a glacier is like that of a river, only slower (about a foot per day in the Alps), and is due to the repeated fracture of the ice by obstacles, and its freezing again (regelation) on renewed contact.	The formation by Glaciers of polished and striated rock surfaces; of Moraines, lateral, median, terminal, and bottom, or ground (*moraine profonde*); of *Roches moutonnées* or rounded bosses of rocks. of Crag-and-tail structure. The deposition of Perched Blocks or Erratics (carried by ice-sheets or by floating ice); —of Boulder Clay or Till, and other forms of glacial drift, often transported from great distances *e.g.*, from the Canton of Valais to Lyons, and the Jura, by the old Rhone glacier. The deepening of many river valleys and lake-beds.

D.—*Continued.*

3. Ice-sheets which fill the valleys and cover the hills, but like glaciers move down to the sea.

   Such continuous ice sheets cover Greenland and the Antartic Continent, and once covered Northern Europe, including the British Isles, except South of London (see page 4)

4. Icebergs, including all forms of floating ice.
   (1) Ground ice, which often lifts up stones as it rises to the surface
   (2) River ice, and coast ice such as the ice-foot, floe-ice, and pack-ice of polar regions
   (3) Bergs or hills of ice often of huge size. These are fragments of the vast polar glaciers pushed out to sea, and broken off by tides and storms.

   These all transport rock-debris, and the bergs plough up the bed of shallow seas.

The formation of many, perhaps most of the lakes and sea-lochs, fjords and firths, in latitudes beyond 40° N. or S. which usually lie in moraine-dammed valleys, or in deep rock-basins, with glaciated shores.

The formation of Kames (eskars or osar) which are ridges of gravel and sand, often miles long and crossing hills and valleys, perhaps due to the melting of the edges of an ice-sheet.

Probably the formation of submarine banks at spots where warm currents meet iceberg-bearing ones, and rapidly melt the ice, so that the debris is dropped; *e.g.*, the Great Bank off Newfoundland, and possibly some of the Boulder Clays of Britain; *e.g.*, those covering the eastern counties.

E. MARINE ACTION.

The waters of the sea and large lakes destroy the land.

(*a*) By chemical action (though but slightly).
(*b*) By the force of its waves.
(*c*) By the force of air compressed by the waves in clefts, caves, and blow-holes.
(*d*) By the battery of gravel, and larger fragments of rock carried by the waves against the cliffs.

The S.E. coast of Yorkshire - of cliffs of boulder clay retreats about 2 yards in a year. The average rate of destruction of the land by the sea is about ten feet in a century, or far less than by sub aerial destruction.

The formation of cliffs, stacks, capes, sea-caves, bays, &c.;

of sand, pebbles, shingle, &c.;

The production of a submarine plain (*Plain of marine erosion*) at or above the level where the destruction ceases (about 300 feet down).

The deposition of marine strata as mechanical sediment (see pages 41, 42, 48).

Such deposits rarely extend to more than 200 miles from the shore; beyond this organic deposits only occur, together with a little water-logged pumice, ashes, and meteoric dust.

Summary. Sub-aërial denudation cuts *vertically*—softer rocks being worn down into plains and valleys, harder rocks left standing in hills and ridges. Marine denudation cuts *horizontally* softer rocks are eaten back into bays, harder rocks stand forward as capes; and plains are at last formed at a moderate depth where erosion ceases. Such submarine plains may later be elevated into plains or even plateaux; or be depressed, and covered by newer strata.

General Proofs of Denudation which afford also some data for estimating its amount. The occurrence of—

1.—River valleys, especially if in plateaux. The Big Cañon of the Colorado is over a mile in depth, though very narrow.

This is "by far the most sublime of all earthly spectacles. It is more than 200 miles long, from 5 to 12 miles wide, and from 5,000 to 6,000 feet deep, the actual gorge being often but a few hundreds of feet wide."

2.—Gorges due to retreat of Waterfalls up stream.

The gorge below Niagara is seven miles long, about 300 yards wide, and 300 feet deep. Lyell estimated the rate of retreat at one foot per year, or 35,000 years in all, and this since the close of the Glacial Period.

3.—Cliffs, Escarpments, Stacks, Caves, and some Straits.

4.—Outliers of strata, isolated from the main mass; *e.g.*, Harrow.

5.—Inliers laid bare by the removal of higher strata; *e.g.*, the Weald.

6.—Plains formed out of folded strata; *e.g.*, Central Ireland.

7.—Hills having a synclinal structure; *e.g.*, Snowdon.

8.—The effacement of all surface indications of faults; a ridge being rarely seen, though it must have existed. (See p. 52).

In some cases denudation may have kept pace with slow fault-motion.

Overlap of the lower or older beds of a formation by the higher or newer beds, which extend successively farther, results from strata being deposited in a sinking area and widening sea, so that the shore line constantly retreats.

Unconformability, or Unconformable overlap, is where one formation rests on the outcrops of a lower and older series of beds, and therefore on a worn denuded surface. Usually the planes of bedding in the two series do *not conform*, but lie at different angles of dip.

An interval of time, more or less great, must have elapsed between the times of deposition of the two groups, and the following stages may be noted:—

1.—The lower beds were deposited horizontally.

2.—These were raised, and often tilted or folded.

3.—Denudation by the eroding action of water, wind and weather, followed or accompanied elevation.

4.—Depression and submergence; followed by

5.—Deposition of the upper group on the denuded surface of the lower.

Such a *Stratigraphical break* is usually accompanied by a *Palæontological break*, or marked change in the fossil remains found in the two groups, the extent of such change affording some idea of the length of the interval which is unrepresented there by deposits, though elsewhere these may occur. Such a break is an imperfection—often a missing volume—in the geological record; and is usually selected as the line of separation between the great geological systems, as shown by * * * in the list of Formations on pp. 4-14.

A Section is a vertical surface of rock showing, *in situ*, the succession and thicknesses of the strata exposed there; or it is a diagram or a verbal description of such sequence in any district, or along any given line of country, constructed from observations on the nature, succession, dip and breadth of outcrop of the strata.

THE ORIGIN OF SCENERY.

The varied scenery of the earth's surface is due to the varied action of the above-named agencies of change, acting on rocks of varied nature, and of unequal hardness.

It depends on (1) the mineral nature of the various strata; (2) the alterations in these owing to consolidation and to metamorphism; (3) the disturbances such as tilting, faulting, folding, undergone; (4) the denudation at various periods and by various agents.

"The three main factors are Deposition, Denudation, and Disturbance; Deposition has produced the material, Denudation has carved it into shape, and Disturbance has defined the mode of Denudation." It is the sea plane, the river saw, the glacier file, the ice wedge, the chisel of heat and frost, aided by the winds and tides, the sea currents, and the fleets of icebergs, freighted with rock débris, from Polar regions that have given the land its present surface features, and are constantly modifying these features. The grand features, however, are largely due to great lines of elevation, alternating with others of depression.

Synclinals are apt to resist denudation, while Anticlinals, being much fissured under strain, are easily denuded; hence "what in geological structure is a depression has by denudation become a mountain like Snowdon, while what is an elevation has been turned into a deep valley." A prophet of old wrote, "Every valley shall be exalted, and every hill made low."

Mountains and Hills form the most striking features of most landscapes. As to mode of origin, they are due to *upheaval*, *denudation*, or *accumulation*.

I.—Mountains and Hills of Upheaval are either—

(*a*) Anticlinal elevations carved by denudation (rare);

Exs.: Mendip Hills, Pennine Hills, Wealden Heights, Jura Mountains.

(*b*) or are due to complex folding and faulting of the strata, which have been usually metamorphosed or even fused, or perhaps igneous rocks have been intruded from below, forming a crystalline core or axis.

Exs.: Malvern Hills, Grampians, Cornish Hills, Alps, and most great chains.

A mountain chain differs from a ridge of hills not so much in height as in origin; the rocks composing it having been slowly crumpled by lateral pressure and lifted to a greater height than they occupy beyond the limits of the chain, whereas Hills proper are rocks left high by the removal of the rocks once surrounding them; *i.e.*, they are hills *owing to denudation*, while mountains are high *in spite of denudation*.

II.—Hills of Circumdenudation are due to—

(*c*) The outcrop of harder strata alternating with softer which latter are more easily removed by denudation.

Exs.: North and South Downs, Cotswolds, Lincoln and York Wolds.

(*d*) The carving out of valleys by streams of water or ice. Table-lands become thus deeply scored by canons and open valleys, and at last are reduced to mere ridges of hills.

The *Dip slope* of a hill range of inclined strata is the long gentle slope. The *Escarpment* is the steep slope, and usually runs in the strike of the beds, thus keeping to the same formation. Such hill ranges always recede with the dip. The Escarpments of the Oolites and Chalk in Mid and South England form very marked features.

The following Table (after Whitaker) compares the distinctive features of escarpments and cliffs.

ESCARPMENTS are due entirely to subaërial denudation.	CLIFFS are due largely to marine denudation.
(*a*) Run along the strike, and so keep to one formation.	(*a*) Run at all angles to the strike, and cut through many formations.
(*b*) Tops are mostly even.	(*b*) Tops are mostly uneven.
(*c*) Form the highest ground of a district.	(*c*) Are mostly backed by higher ground.
(*d*) Often have springs at their foot, but rarely the sea.	(*d*) Have the sea at their foot, and their bases at or near the sea-level
(*e*) Often run in winding lines, the lines of outcrop of the strata	(*e*) Run nearly straight or in gentle curves (bays), except where the rock changes its nature, or where a valley breaks through.
(*f*) Rivers begin at or near them, *i.e.*, water flows from them.	(*f*) Rivers end at them, *i.e.*, water flows towards them at last.

Outliers are isolated patches of some one formation cut off by denudation from the main mass, and so, of course, *surrounded by strata of older age.*

These are usually but not necessarily hills: *e.g.*, Hampstead Heath, Harrow-on-the-Hill, and the Langdon Hills, all of Bagshot Sand on London Clay.

Inliers are similar patches *surrounded by strata of newer age*, and laid bare owing to greater denudation than these.

These are usually but not necessarily valleys, and often *anticlines* or *periclines*; *e.g.*, The Weald, the Woolhope Valley near Hereford.

III.—Hills of Accumulation are such as are heaped up—

(*e*) By volcanic eruptions, the ejected materials being piled up around the crater into a conical hill.

(*f*) By actions of winds on sands; *e.g.*, the sand dunes of the Landes, of the great deserts and along the coasts of Norfolk, Dorset, Devon, &c.

THE AGE OF MOUNTAINS.

This must be distinguished from the age of the Strata of which they are built, which may be far more ancient. Some mountains are of great antiquity, but such are usually of no great height, being but the basal wrecks of what they once were; others are comparatively modern; but all have been of slow growth, or rather upheaval, and periods of rest, and even of depression, have supervened.

The *Scandinavian Chain*, including the *Scottish Highlands*, now severed from the main chain, existed as high lands before and during the deposition of the Old Red Sandstone.
The *Urals* probably rose during the Permian Period
The *Alleghanies* began to rise before the Triassic Period.
The *Rocky Mountains* date chiefly from the Middle Tertiary.
The *Andes* rose after the deposition of our chalk.

The great East and West chain of Europe-Asia—the *Pyrenees*, *Alps*, *Caucasus*, *Himalayas*, *&c.*—is the most modern of the great mountain axes, having been elevated in great part after the Miocene Epoch, and consisting largely of Oolitic, Cretaceous and Nummulitic (Eocene) strata, the latter at heights of even 10,000 feet in the Alps.

The following high lands in Great Britain consist largely of, or at least owe their height chiefly to the occurrence of, the rocks named :—

1. Intrusive Igneous rock—Granite, Syenite, Diorite, Felstone, Basalt—with crystalline Schists, in the *Grampians*, *Pentlands*, *Cheviots*, *Charnwood Forest*, *Cumbrian Mountains*, *Cambrian Mountains* in Carnarvon and Pembroke, *Malverns*, *Dartmoor* and the *Cornish Heights*.
2. Interbedded Volcanic ashes, tuffs, &c., in the *Ochil* and *Sidlaw Hills*, *Cumbrian Mountains*, *Snowdon*, and *Hills of Merioneth*
3. Archæan, Cambrian and Silurian Strata in the *Highlands*, *Cumbrian* and *Cambrian Mountains*, *Longmynd* and *Caradoc Hills*, *Wrekin*, *Malverns*
4. Devonian strata in the *Black Mountains* of Brecon, the *Quantocks*, *Exmoor* and *Cornish Heights (?)*.
5. Carboniferous strata in the Hills around Edinburgh and Glasgow, the *Cheviots*, *Pennine Chain* and *Peak* district, *Clee Hills*, *Forest of Dean* and *Wye Cliffs*, *Clifton Rocks*, *Mendips*, *Hills of Mid-Devon*.
6. Marlstone or Mid Lias in *Edgehills*, and *Cleveland Hills* of Yorkshire.
7. Oolitic strata in the *York Moors*, *Cotswolds*, Portland.
8. Hastings sand in the *Wealden Heights*, ending at *Fairlight Head*.
9. Greensand in the *Blackdown* and *Dorset Heights*, ***Leith Hill*** and ***Hindhead*** in Surrey.
10. Chalk forms—the *York and Lincoln Wolds*, *East Anglian* and *Chiltern Hills*, *Marlborough Downs*, *Salisbury Plain*, *North Downs*, *South Downs*, *Isle of Wight Downs*.

Valleys are depressions in the earth's surface, the larger and deeper ones being filled with the sea or inlets of it, the rest mostly with streams and often with lakes.

They are variously termed—vales, dales, dells, combes, wadys, chines, glens, gorges, ravines, canons, passes and plains. When submerged they may be channels, straits, sounds, gulfs, fiords, firths.

They are due to (*a*) subsidence owing to earth movements, or to solution of rocks beneath by underground streams. (*b*) Faults and joints, which rarely do more than decide the course of a river. (*c*) Denudation, always the chief, often the only cause of a valley.

Transverse valleys run *in the dip* of the beds, and so cross successive strata. Longitudinal valleys run *in the strike*, and along the outcrop of the softer beds.

The main streams mostly run "across the grain" of a country; the feeders run "with the grain." This is well seen in the streams of the Wealden area, which reach the sea by cutting through the chalk escarpments, to the North or South by gorge-like valleys These rivers are older than the present hills, and began to cut the valleys when the line of highest ground was at or near the sources of the streams, and far above the line of the existing Wealden Heights. This line of watershed has been lowered by denudation, and with it the rivers and their valleys, while the North and South Downs have receded (about 15 miles), and continue to recede from the axis of the anticline.

Plains are low-lying and fairly level areas due to (*a*) marine denudation cutting back the land horizontally (p. 55). (*b*) Deposition of Alluvium over the flood-plain of a river, or in its shallow estuary.

Exs.: The Eastern Counties (of chalk covered with glacial drift), the Midland Counties (of Lias with much drift), the Cheshire Plain, the Plain of York, and the Severn Valley (all of Trias); the Central Plains of Ireland and Scotland (of Carboniferous Limestone, Shales, &c.)

Plateaux are usually plains of marine denudation, or rarely plains of deposition, elevated much above sea-level, and rendered more or less uneven by the denuding action of weather and streams.

Exs.: Bavaria, Spain, South and Central Africa, the Canon Region of the Colorado.

Continents are the large land areas, viz: Eurasia with Africa, Australia, the Americas, and Antarctica (?).

Their mean height is about 1,200 feet, while the mean depth of the oceans is about 12,000 feet,* but the zero plane, or original surface of the globe before it became wrinkled, lies about 7,000 feet below the present sea level; the continental areas were early raised above, and the ocean beds depressed below this, and have probably undergone but moderate changes in level as a whole since, though the margins have oscillated in level frequently (see p. 50).

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* Dr. Murray of the *Challenger* gives the former as 2,230 feet, the latter

Islands are smaller land areas originating as

(1) Fragments of continents, severed either by denudation or by subsidence. Exs.: All large islands.

(2) Accumulations of the débris from submarine volcanoes.

(3) Accumulations of the calcareous skeletons of coral polypes living near the shore line of tropical coasts, or on submarine banks (see p. 50).

The former class (*Continental Islands*)* differ from the two latter (*Oceanic Islands*), in that they consist chiefly of sedimentary rocks, which, like the indigenous animals and plants, resemble those of the adjacent parent continent. The channel of separation is usually narrow and shallow, but may be wide and deep where the severance is ancient, in which case the Fauna and Flora are more unlike; as in Madagascar, severed from Africa in early Tertiary times, and now separated by the Mozambique Channel, 250 miles wide, 2 miles

The **Ocean** is the great water-covered area of the earth's surface, its five chief divisions being also called oceans.

Its total area is about 144 millions of square miles, but the true ocean basins are less, since these rarely commence near the present shore line, along which often extends a submarine plain, which may now and again become dry land. The deep basins have an average depth of about 2,000 fathoms (2¼ miles), and a greatest known depth of 4,500 fathoms (5½ miles). These receive little deposit of sediment, and probably undergo little changes of elevation; but volcanoes often originate here, and may attain enormous height and bulk, as in the Sandwich Isles

Seas are water areas more or less enclosed by land but connected with the ocean (except a few salt lakes).

Some shallow seas are but slightly depressed parts of the adjacent continent, *e.g.*, North and Baltic Seas; others are deep basins, often trough-like, and mostly ancient features, *e.g.*, the East and West basins of the Mediterranean, the Caspian (South part), Red Sea, Sulu Sea, Caribbean Sea

Lakes are water areas surrounded by land.

They either have no outlet, evaporation or percolation removing the surplus water, or the outlet is an effluent stream of relatively small size, not an open strait. There are four chief varieties (1) *Fresh*, with an outlet; (2) *Salt*, with no outlet, and mostly on arid table-lands; (3) *Inland Seas*, salt, occupying depressions, and often very deep; (4) *Lagoons*, of salt or brackish water, skirting low shores near the sea, *e.g.*, coasts of Germany, Denmark, Holland, Spain, Hindostan, United States

Lakes classed as to their origin are either

I.—Those filling hollows enclosed in part by superficial deposits—mounds of sand, gravel, beach shingle, moraines; or else glaciers, avalanches, or lava streams which have obstructed valleys.

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* The chief *Continental Islands* in order of size are:—Greenland, Borneo, Papua, Madagascar, Sumatra, Niphon, Great Britain, Celebes, Java, Cuba.

II.—Those which lie in true rock-basins formed (1) by glacier erosion in valleys or plains at the foot of mountains; *e.g.*, most of the lakes in Europe to North of 52° lat., and in America to North of 42°, and thickly scattered over Scotland, Scandinavia, Switzerland, North Germany, Finland, Canada.

(2) by subsidence owing to earth movements or to faults—probably the great lakes of Central Africa and of Canada.

(3) by solution of soluble strata by rivers or underground streams, *e.g.*, the Shannon lakes, Cheshire meres.

(4) by elevation of the mouth of a valley, *e.g.*, L. Titicaca, Great Salt L.

Many salt lakes are fragments of the ocean, and often still contain marine animals, *e.g.*, the Caspian, area 180,000 sq. miles, 3,000 feet deep in its southern half, surface 85 feet below that of Black Sea. Its waters are salt (1 per cent.), seals live in it, and shells of Arctic species are scattered widely around it, as far as the Sea of Aral, and thence to the Arctic Ocean.

PALÆONTOLOGY

Is the study of fossil beings; and treats of the living beings—animal and vegetable—which have inhabited the earth at past periods in its history.

A **Fossil** or "petrifaction" is any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes.

The term is usually made to exclude remains found in deposits formed during the Historical Period, such remains being called Recent.

Fauna and **Flora** mean the entire assemblage of the Animals and of the Plants respectively belonging to a particular region, or to a particular period.

The existing animals and plants of the world are distributed in six biological regions or Botanical and Zoological Provinces.

1. *Palæarctic*—all Europe, the temperate parts of Asia, and Africa north of the Sahara.
2. *Ethiopian*—the rest of Africa, with Arabia and Madagascar.
3. *Oriental*—Asia to east of the Persian Gulf, including most of the Malay Archipelago.
4. *Australian*—including Australia and all islands to the east and south of Borneo and Java (Wallace's line). The Australian continent probably included formerly Celebes, Papua, Norfolk I., New Zealand, Tasmania.
5. *Neotropical*—all South and Central America, with the West Indies.
6. *Nearctic*—all North America beyond the tropics.

In the first three the existing and the extinct forms of life are mostly very unlike, while in the next two they are very similar, save that the extinct forms were often of gigantic size. In the Australian Region there are no indigenous apes or monkeys, no Carnivores, Ruminants, nor Pachyderms, but four-fifths of the Mammals are Marsupials—Kangaroo, Wombat, Flying Opossum, Native Devil, &c. The plants of Australia include Tree-ferns, Cycads, *Acacia*, *Eucalyptus* (gum-tree), and many heath-like plants; but no bread-yielding plants occur, and few edible fruits.

Fossilisation or Petrifaction refers to the particular state of preservation of fossils, whether (1) the real bodies, altered merely by pressure, or by loss of soft parts, or owing to infiltration and addition of mineral matter;

These occur mostly in clays which preserve them from air and water.

(2) "casts" or moulds of the exterior form, or of the internal cavity;

The actual body, *e.g.*, a shell, may be removed in solution after the casts are formed, and so leave the internal cast loose, and the external cast on the surrounding rock; or the cavity may be afterwards filled with mineral matter from solution, similar to or different from that of the surrounding rock.

or (3) models formed by slow replacement, particle by particle, of the whole of the original body by some mineral substance, leaving an exact model, not only as to external form, but often as to minute structure. The replacing material may be *silica, calcite, iron pyrites, iron oxide, iron carbonate, and even sulphur, malachite, vivianite, &c.*

Wood, shells, corals, sponges, may thus be *silicified* or converted to flint, or *calcified*, or *pyritized*; and wood, leaves, &c., are often *carbonized*.

NOTE.—When fossils occur in an imperfect state, they may have been broken as prey, drifted by currents, or worn by shore-action.

Drifted fossils may of course occur in strata to which they do not belong, *e.g.*, Lias fossils occur North of London, in glacial drift, on the London clay.

Fossils are often found in the petrified droppings (*coprolites*) of fishes, and reptiles, which consumed them as prey; bones are found buried in the stalagmite floors of limestone caverns of Post Tertiary age, having often been gnawed by cave-dwelling beasts of prey—hyænas, lions, bears.

THE CHIEF CLASSES OF PLANTS.

I.—CRYPTOGAMS are flowerless plants, bearing *spores* which, unlike seeds, contain no embryo plant, and are very minute.

1. **Algæ**—sea-weeds, &c. Occur fossil from the Cambrian Period. Some, which secrete mineral matter, form rock-deposits, *e.g.*, *Corallines* and *Nullipores*, with calcareous incrustation; *Diatoms*, with beautiful siliceous cases (frustules); *Chara*, with encrusted stems and fruits (*Gyrogonites*).

Chara is widely diffused in time and space in fresh-water deposits.

Eophyton, a fucoid of L. Cambrian age in Sweden, is the oldest known plant, but all Pre-tertiary forms are of doubtful nature; though from the abundance of vegetable-feeding Molluscs in most old rocks Algæ were probably also abundant.

2. **Fungi**—mushrooms, lichens, &c. Are rare as fossils.

3. **Mosses** may form beds of peat—of *Sphagnum*, the bog-moss.

4. **Ferns** occur fossil, often abundantly and of tree-like size, from Devonian or Silurian times (*Adiantites* in Kilkenny.)

NOTE.—Their names often end in *'pteris: Eopteris, Neuropteris, Caniopteris*

5. **Equisetites** or horse-tails, with jointed stems much silicified and whorls of leaves. Forms of great size, *Calamites*, *Asterophyllites*, *Equisetites*, occur in the Newer Palæozoic rocks; and others, *Equisetum*, in the Trias and newer rocks to the present.

6. **Lycopods** or Club-mosses, though small now, are among the largest and most abundant of Carboniferous plants; their resinous spores and sporangia alone form whole beds of coal, and their stems and foliage help largely to form others.

They date from U. Silurian, where occur *Lepidodendron*, *Pachytheca (?)* Later forms were *Sigillaria* (stem) with *Stigmaria* (roots), *Halonia*, *Ulodendron*.

II.—Gymnosperms are Flowering plants *(Phanerogams)*, bearing naked seeds, *i.e.*, not contained in a seed-vessel (ovary).

7. **Cycads**, palm-like plants with hard leaves, easily preserved.

They date from Permian times, and the Mesozoic periods formed "The Age of Cycads." Genera: *Pterophyllum*, *Zamites*, *Cycas* (the latter still living).

8. **Conifers**—firs, pines, yews, &c.—with resinous wood (the fibres of which have peculiar markings), and usually cone-shaped fruits, or solitary ones like *Trigonocarpum*.

Genera: *Pinites*, *Dadoxylon*, *Araucarioxylon*, *&c.* *Sternbergia* is a pith-cast. They date from the Devonian, but were first abundant in Permian times.

III.—Angiosperms are Flowering plants, bearing true seeds within a *closed* seed-vessel (ovary).

9. **Monocotyledons** or **Endogens**, the stems having many small wood bundles crowded in the outer part.

Exs.: Grasses, Palms, Lilies, Arums. They date from Carboniferous age

10. **Dicotyledons** or **Exogens**, the stems having the wood-bundles in a ring, and growing *outwards*, forming annual rings of growth, as in all our shrubs and forest trees. They date from U. Cretaceous and abound in Tertiary strata.

Classes 4–6, the Vascular Cryptogams, are very abundant in the Palæozoic; 7 and 8 in the Mesozoic; while Classes 9 and 10 are nearly confined to the Cainozoic formations.

THE CHIEF CLASSES OF ANIMALS.

I.—Protozoa, small animals of a jelly-like substance, in many cases secreting beautiful shells, usually perforated, which shells alone can be preserved as fossils.

Class I.—**Rhizopoda** (root-footed) including besides soft forms—

(1.) **Foraminifera**, having mostly calcareous shells.

These date from Silurian and possibly Archæan times (*Eozoon*), and are very abundant, often forming thick beds of limestone covering vast areas. *e.g.* Chalk of Cretaceous age, Nummulitic Limestone of Eocene age, Atlantic ooze still forming.

ina, *Miliola*, *Lagena*, *Fusulina*, *Nummulina*, *&c.*

(2.) **Radiolaria,** having siliceous shells of great beauty.

Genera: *Actinomma, Podocyrtis, Haliomma.* See "Barbadoes Earth," page 45.

II—SPONGIDA. Class 2. **Sponges,** soft animals with an internal skeleton of horny fibres, or of spicules of lime or of silica.

The latter kinds occur abundantly as fossils from Cambrian period, especially in the L. Greensand at Farringdon, *Manon, Peronella, &c.*, and in the chalk, chiefly in flints, *Siphonia, Ventriculites.*

III.—CŒLENTERATA, simple or compound animals with a distinct body-cavity, and often a firm stony skeleton of radial plates or of tubes, or of both these.

Class 3. **Hydrozoa,** including Jelly-fishes, Millepore corals, and probably **Graptolites,** which had pen-like horny skeletons, the glistening impressions of which, in pyrites, are common in Silurian rocks.

Genera: *Monograptus, Diplograptus, Didymograptus, Dictyograptus, Rastrites.*

Class 4. **Actinozoa,** including Sea-anemones, Sea-fans, and Corals; the latter may be single as in the Mushroom corals (*Fungia*), Cup-corals (*Caryophyllia*, &c.), or compound as in the reef-building corals (*Astræa, Meandrina*, &c.)

The RUGOSE (wrinkled) corals, so abundant in the Palæozoic limestones, so rare since, had the calcareous partitions (septa) arranged in fours (Tetracoralla).

Exs.: *Cyathophyllum, Omphyma, Lonsdaleia*, possibly *Michelinia, Holocystis.*

In the HEXACORALLA the septa are in sixes. Exs. *Madrepora, Favosites, Fungia.* In the ALCYONARIA or OCTOCORALLA the septa are in eights. Exs.. Red coral, *Heliopora, Heliolites.*

IV.--ECHINODERMATA, Class 5, usually 5-rayed animals with a rough skin strengthened by calcareous particles, or by plates so fitted as to form a shell covered with movable spines.

The class includes—

(*a*) fixed forms, mostly with jointed calcareous stalks.

(1) *Crinoids* or Encrinites, "Sea-lilies," ranging from Cambrian, abundant in Carboniferous and Jurassic, rare now, *Actinocrinus, Pentacrinus, Apiocrinus.*

(2) *Cystideans* and (3) *Blastoids*, found in Palæozoic only.

(*b*) free forms, viz.: (4) *Star-fishes*; and (5) *Brittle-stars.*

(6) Sea-urchins (*Echinoidea*) with spine-covered shells, either regular in shape, as *Echinus, Cidaris, Hemicidaris, Diadema*; or irregular ("Heart-urchins,") as *Spatangus, Micraster, Ananchytes, Echinoconus* (*Galerites*).

The Roman numerals I., II., III., &c., refer to the greater groups commonly called Sub-Kingdoms or Series. The numbers in brackets refer to sub-divisions of the Classes, commonly called Orders, but which are, in many cases, considered to rank as Classes by other authors.

(7) Sea-cucumbers, *e.g.*, Trepang (*Holothuria*). Rarely fossil.

V.—VERMES or Worms. The chief fossil forms belong to

Class 6. **Annelida,** especially the tube-dwelling forms (*Tubicolæ*).

Genera: *Serpula, Spirorbis, Ditrupa;* and probably the Cambrian *Arenicolites.*

Class 7. **Polyzoa,** small compound animals, common in rocks of all ages, encrusting shells, or free, and aiding largely in the formation of some limestones. The mis-called Coralline Crag is rich in Polyzoans.

These resemble corals, but are of higher organisation, and are often grouped with Mollusca, or with Brachiopods as the sub-kingdom Molluscoida.

Exs.: *Fenestella* the "lace-coral," *Polypora, Lepralia, Theona, Fascicularia.*

VI.—ARTHROPODA, ringed animals (*Articulata*), with jointed limbs and a hard skin of chitin, often calcified.

8. **Crustacea,** the jointed Shell-fish, with many paired-legs, gills, and a firm crust. The chief groups are:—the Lobsters, Crabs, the King-crabs—*Limulus, Prestwichia,* Barnacles—*Lepas, Balanus;* Phyllopods—*Hymenocaris, Estheria;* and Ostracods, including Entomostraca—*Cypris, Cythere;* and in the older strata the Eurypterids—*Eurypterus, Pterygotus;* and above all the **Trilobites** (page xiv. of Drawings and note on page 69).

This class being mostly aquatic, and the shell calcified, is very abundant in the fossil state, and dates from the Lower Cambrian (*Paradoxides*).

9. **Arachnida,** including Spiders and Scorpions, both dating from the Silurian—*Palaranea* and *Eoscorpius.*

10. **Myriapoda,** including Centipedes and Millipedes, with very many paired limbs. The class dates from the Carboniferous.

11. **Insecta,** including beetles, flies, moths, bees, &c., and mostly having distinct head, thorax, abdomen; six legs and four wings.

Insects date from the Silurian age in France, the Devonian age in America, and are first found in Britain in the Coal Measures, quite commonly in the Jurassic rocks, and abundantly in the Tertiary strata. Beautifully preserved forms occur in Amber, a fossil resin of Mid-Tertiary or Post-Tertiary age.

VII.—MOLLUSCA, soft-bodied animals enclosed in a tough muscular skin (mantle), and usually covered with a calcareous shell often very thick and of great size, either in one piece or in two "valves."

The Molluscan "shell fish" are the most abundant, and to the geologist the most valuable of fossils; for

1st. They usually form very durable shells, horny (*Lingula*) or calcareous.

2nd. Being mostly aquatic they are more likely to be preserved in aqueous rocks than terrestrial forms.

3rd. The freshwater forms being unlike those found in brackish water, and in the sea, their presence enables us to distinguish between lacustrine, estuarine, and marine deposits. (See pp. 2—3.)

4th. No one species has any great range in time; its horizon is limited.

5th. The geographical range of each kind is usually very great, so that it is very likely to occur in rocks formed at the same time in places far apart. N.B.—The range in space of any species is usually great, though its range in time is always small.

Marine forms date from Cambrian (*Lingula*).
Freshwater forms from Devonian (*Anodonta*)
Land forms from the Coal Measures (*Pupa*)
} Each of these genera still lives.

12. **Brachiopoda,** "lamp-shells," having bivalve shells, the valves placed front and back, each symmetrical but usually unequal, the front one with a beak.

For distinctions between, and range of, the chief genera see note on p. 70.

13. **Lamellibranchs,** differing from the last class in—breathing by leaf-like gills, the two valves of the shell being usually equal, often unsymmetrical, and placed right and left.

The forms with but one shell-muscle (monomyary) occur only in the sea; as *Ostrea*, oyster, *Gryphæa*; those with two (dimyary) may occur in either salt water, as *Cardium* (cockle), *Mytilus*, *Cyprina*; or in freshwater; as *Unio*, *Anodonta*, *Cyrena*. *Pholas* and *Teredo* are destructive boring shells.

14. **Gasteropoda**—snails, whelks, cowries, &c.—having univalve shells, usually spiral, breathing either by gills or in the land and freshwater forms, by a lung-sac—*e.g.*, Snail.

Carnivorous forms, all marine, may be known by the notched mouth or canal to the shell which marks the presence of a respiratory tube or siphon. Entire-mouthed forms (Holostomata) have no such siphon, and are usually herbivorous. Certain oceanic forms (Heteropoda) swim freely, as did the extinct *Bellerophon*.

15. **Pteropoda,** oceanic forms swimming by a pair of wing-like fins

Fossil forms are few, but include *Tentaculites*, *Theca*, *Conularia*, *&c.*

16. **Cephalopoda**—nautilus, octopus, cuttle-fish—most having long arms bearing suckers around the mouth, which contains powerful jaws. The external shell when present is many-chambered; when absent there is often an internal "pen" or bone, *e.g.*, cuttle-bone, *Belemnites*. The class is marine.

There are two groups:—(1.) The Dibranchiate or 2-gilled forms, including all but one of the existing forms, and attaining sometimes gigantic size. In these, except the paper nautilus, there is no external shell, and except the *Belemnites* they are rare as fossils. (2.) The Tetrabranchiate or 4-gilled forms, with chambered shells. These include the living pearly Nautilus and the extremely abundant fossil *Nautili*, *Ammonites*, *Orthoceratites*, &c. (See p. 70.)

The above classes, with others of less importance, collectively form the INVERTEBRATA.

VIII.—*VERTEBRATA, animals with jointed bony skeleton, especially a "back-bone" or column of vertebræ. Limbs jointed, 2 pairs, or reduced to 1 pair or 0; these may be arms, legs, wings, fins, paddles, &c.*

Class 1—**Fishes,** oviparous, cold-blooded, scale-clad, breathing by gills; tails diphycercal, heterocercal, or homocercal.

Fishes date from the Lower Ludlow rocks of U. Silurian (*Pteraspis Ludensis*), unless the tooth-like "Conodonts" of Cambrian age, from Russia, be such.

The chief groups are the Teleosteans, with bony skeletons—most modern fishes; the Elasmobranchs with cartilaginous skeleton, and no true scales, though their spines are common as fossils (*Ichthyodorulites*)—sharks, rays; the Chimæroids *Rhynchodus*; the Ganoids usually clad in plates of bone often sculptured and enamelled. This group includes most of the Palæozoic and Mesozoic fishes, as also a few living forms sturgeon, &c. Ganoids formed the most striking feature of the fauna of the Devonian and Carboniferous seas and lakes. (See p XV.)

Class 2—**Amphibians** with the character of fishes in the young or tadpole stage, and of reptiles in their adult state. Besides the Batrachians—frog, toad, &c., and the recent tailed forms—newt, salamander, axolotl; there were *Labyrinthodonts*, bone-clad forms with peculiar teeth, and often of colossal size—*Anthracosaurus*, *Mastodonsaurus*—but found only in Carboniferous, Permian and Triassic rocks.

Class 3—**Reptiles**—cold-blooded, breathing by lungs, and clad with horny scales or bony plates (scutes). Of the ten orders known four only still live.

1.—Tortoises and turtles, dating from the Jurassic period.

2.—Snakes and serpents, not known to have existed before Tertiary times.

3.—Lizards, including the Permian *Protorosaurus* (the earliest known reptile), the Triassic *Telerpeton*, and the gigantic Cretaceous *Mesosaurus*.

4.—Crocodiles, including the *Stagonolepis* of the Trias, *Teleosaurus* of the Oolite, and the *Goniopholis* of the Cretaceous.

The chief extinct orders, all Mesozoic only, are:—

5.—*Ichthyosauria*, from the Trias to Chalk 6.—*Plesiosauria*, Trias to Chalk.

7.—*Ornithosauria* or *Pterosauria*, flying reptiles (dragons)—*Pterodactylus*, &c., from the Lias to Chalk; *Rhamphorhynchus*, of Oolitic age.

8.—*Dinosauria*, huge reptiles abounding in Mesozoic times, and confined to these. Exs. *Iguanodon*, *Megalosaurus*, *Hylæosaurus*, *Cetiosaurus*. The *Atlantosaurus*, of Jurassic age in America, was probably 100 feet long, and stood 30 feet high.

Class 4—**Birds**—warm-blooded, breathing by lungs, and clad in feathers; toothless, except in the earliest known forms from Bavaria, Kansas, and Eocene forms from Sheppey I.

The earliest known form is the *Archæopteryx* of the U. Oolites (p. 9), which had a long bony tail, with large feathers on either side. It was toothed, and strikingly reptilian in appearance. The largest birds known are the recently extinct Moa (*Dinornis*) of New Zealand, 10—12 feet high, and allied to the ostrich, emu, and other running birds, and the *Æpiornis*.

Class 5—**Mammals**—With the above characters of birds, but viviparous (not hatched from eggs), and clad in hair (wool, fur, quills, &c.), or naked. The earlier forms were, like nearly all the existing Australian forms, (1) **Marsupials**, having pouches for carrying the very imperfect young. The marine forms include (2) **Cetaceans**—whales, porpoises, dolphins; also (3) **Sirenians**—manatee, &c.; also certain **Carnivora**—seals, walrus, &c. Other important groups (orders) are the (4) **Edentates**—sloth, *Glyptodon*, *Megatherium*; (5) **Insectivores**—mole, *Stereognathus*; (6) **Bats**; (7) **Rodents**—vole, beaver (*Castor*), hare (*Lepus*), mouse; (8) **Ungulates** (hoofed)—including horse, pig, *Rhinoceros*, *Tapir*, *Palæotherium*; also the **Ruminants**—ox (*Bos*), elk, deer (*Cervus*); and the **Proboscideans**—elephant, *Mastodon*, *Dinotherium*; (9) **Carnivores**—lion (*Felis*), cat, dog (*Canis*), bear (*Ursus*), *Hyæna*. The highest order, (10) **Primates**, includes monkeys, apes and man (*Homo*).

Mammals date from the Triassic *Microlestes*; they have next been found in the Great Oolite ("Stonesfield Slate"); then in the Purbeck Oolites; and not again till the Eocene strata, when non-marsupial forms first become abundant.

Man certainly lived in Western Europe in early Postglacial times, probably in Inter or Mid-glacial times (about 200,000 years ago), and possibly—though improbably—in Pre-glacial (Pliocene and Miocene) times. (See p. 5.)

NOTE ON TRILOBITES.

These Crustaceans are confined to the Palæozoic strata, where they are extremely abundant, and vary in size from that of a pin's head to over two feet in length. The eyes are compound (with from 15 to 15,000 facets), and they probably had swimming paddles, as in the Lobster, &c., their impressions being known.

hree regions, each more or less 3-lobed (hence the name—Tri-lobite).

The *Cephalic Shield*, covering the head often with two lateral spines, and

2. The *Thoracic segments*, or body-rings, from two to 26 in number, all separate, and each consisting of an *axis* and two *pleuræ*

3. The *Pygidium*, or tail-shield, of from two to 28 rings united.

Chief genera: ***Paradoxides*** and ***Olenus*** of Cambrian age; ***Asaphus*** and ***Ogygia*** of Lower, ***Phacops*** and ***Calymene*** of Upper Silurian age; ***Bronteus*** and ***Harpes*** of Devonian age; and ***Phillipsia*** and ***Griffithides***, of Carboniferous age.

NOTE ON BRACHIOPODS.

These bivalve Molluscs, so abundant in the Pre-Tertiary strata, especially the Palæozoic, are now nearly extinct. (See page xvi.)

The chief distinctions between the different genera are often in the internal structure, especially the fringed arms and the spiral or looped stony processes. The following characters refer to the shell:—

In *Lingula*, tongue-shaped, flat, and horny. Cambrian to Present.

In *Rhynchonella*, sharply plaited and with pointed beak Silurian to Present.

In *Terebratula*, "lamp-shell," oval, smooth, or folded, with a large round hole (foramen) in the beaked (or ventral) valve. Devonian to Present.

In *Spirifera*, folded and often plaited, with long, straight hinge-line (Name from two large spiral stony coils within). Silurian to Permian. The related *Spiriferina* (*e.g.*, *S. Walcottii* of the L. Lias) ranges from Trias to Oolite.

In *Productus* the shell is rough or spiny, much curved, the dorsal valve concave, the beak very prominent, and the hinge-line straight. Devonian to Permian. Species *P. giganteus*, *semireticulatus*, *horridus*.

In *Atrypa* usually one valve is nearly flat, the other much bulging, and both finely grooved. In *Orthis* the hinge-line is straight and wide, the valves nearly flat. In *Strophomena* the valves are finely grooved, at first nearly flat, then abruptly bent, so that the dorsal valve is depressed.

The three latter genera range from Silurian to Carboniferous.

NOTE ON CEPHALOPODS.

The chief fossil genera belong to the families **Nautilidæ** and **Ammonitidæ**, and are known chiefly from their chambered shells.

In *Nautilus* the shell is coiled in a flat spiral, the septa or partitions are concave outwards, the sutures plain, or in *Aturia* with deep side lobe, the siphuncle (or tube connecting the chambers) central. Silurian to Present.

The *Orthoceras* is similar, but shell straight (xiv. 14). Cambrian to Trias.

In *Clymenia* the sutures are simple; siphuncle internal. Devonian.

In *Goniatites* the sutures are angular, siph. dorsal. Devonian to Permian.

In *Ceratites* the sutures are crenated, scarcely foliated. Mid-Trias only.

In *Ammonites* the septa are convex, the sutures wavy or leaf-like (foliated), and the siphuncle dorsal. Trias to Cretaceous. Recent writers have grouped the old genus *Ammonites* into several families, including 38 genera, with some 600 species; *e.g.*, *Amaltheus*, *Arcestes*, *Arietites*, *Hamites*.

In the Cretaceous rocks, where the family Ammonitidæ became extinct, many remarkable aberrant forms occur—*Turrilites*, with spiral, turreted shell; *Baculites*, with straight, staff-like shell, *Hamites*, with shell bent twice like a hook (xiii. 12); *Scaphites*, with boat-like shell; *Ancyloceras* and *Crioceras*, with variously curved shells.

Another form of Cephalopod, very abundant in Mesozoic strata—Lias to Chalk,—is *Belemnites* or "thunderbolt," the conical internal "guard" of a kind of cuttle-fish, containing at one end a conical chambered piece, the "phragmacone," and sometimes above it an ink-bag of sepia. Water-worn specimens are common in many Post-Tertiary gravel and drift deposits.

ORGANIC REMAINS OR FOSSILS

AND INDUSTRIAL PRODUCTS.

Most of the fossil forms referred to below are figured in the "Tabular View of British Fossils" (Stanford), in all the larger manuals, and a few in these notes on pp. xiii. to xvi. About 10,000 species of fossils are found in Britain.

The study of museum and students' collections of fossils is an essential accompaniment to the use of these descriptive lists.

THE ARCHÆAN OR PRE-CAMBRIAN PERIODS.

The **Archæan** rocks of Britain (p. 15)—Pebidian on Dimetian—are, in part, volcanic accumulations on the land, in part gneiss; and unfossiliferous or **Azoic**, *i.e.*, without life.

The **Laurentian** rocks of Canada contain a doubtfully organic structure, possibly a reef-building Foraminifer *Eozoon Canadense*, hence are **Eozoic.**

The **Huronian** rocks resting on Laurentian gneiss have yielded no fossils.

The **Taconian** rocks of America contain fossils, *Paradoxides*; *Olenellus*

Products—road-metal, lime; in Canada, iron, black-lead.

I.—THE PALÆOZOIC OR PRIMARY PERIODS.

"The Era of Brachiopods, Orthoceratites, Trilobites."

(For the general character of the fossils see p. 16.)

The Lower Palæozoic or Cambro-Silurian series contains three successive Faunas, each characteristic of a great group or *System* of strata, and formed in three successive *Periods* of time. Similarly, there are three Upper Palæozoic Periods and Systems. Down to 1888, 6,022 British Palæozoic species are known.

Period 1.—**Cambrian,** with the first or Primordial fauna—Sponges; Trilobites (*Paradoxides*, *Olenus*); Brachiopods (*Lingula*, *Orthis*); and Pteropods (*Theca*).

The **Lower Cambrian** contains (chiefly in the Harlech and Menevian rocks of St Davids) *Protospongia*, *Arenicolites* and *Serpula* (worms), *Paradoxides aurora*, *P. Davidis*; *Plutonia Sedgwickii*, and other Trilobites, *Lingulella primæva*, *ferruginea*; *Orthis*, and other Brachiopods, *Theca antiqua*, *T. corrugata*, and other Pteropods.

The **Upper Cambrian** (Lingula flags and Tremadoc beds) contains numerous Trilobites *Olenus micrurus*; *Agnostus trinodus*, *pisiformis*; *Angelina Sedgwickii*; *Asaphus Homfrayi*; *Niobe Homfrayi*, a shrimp *Hymenocaris vermicauda*; the Brachiopods *Lingulella Davisii*, *Orthis Carausii*, the Pteropods *Theca obtusa*, *ovata*; the Gasteropod *Bellerophon*; and the first Cephalopod *Orthoceras sericeum*.

Products—The valuable slates of Penrhyn and Llanberis: graphite, gold, and various metallic ores in veins.

Period 2.—**Ordovician** or **Lower Silurian.**

(*a*) Arenig beds. (*b*) Llandeilo beds. (*c*) Bala beds.

"The Age of Graptolites, Trilobites, Cystideans."

Marine life had now become abundant and varied, nearly every class of Invertebrate animals being represented; Brachiopods and Trilobites swarmed everywhere.

The quill-pen-like Graptolites (Class 3)—*Didymograptus; Diplograptus; Dicellograptus;* Cystidean Echinoderms—*Echinosphaerites; Sphaeronites;* and Trilobites especially abounded. Of the latter 40 genera, with 200 species, occur—*Asaphus tyrannus; Ogygia Buchii; Trinucleus Gibbsii, Lloydii, concentricus.* Corals were few, but Brachiopods (170 sp.) swarmed in the seas—*Lingula; Leptaena; Orthis calligramma, alata.* Gasteropod spiral shells—*Murchisonia; Euomphalus; Bellerophon,* and Cephalopod chambered shells (60 sp.)—*Orthoceras mendax, vagans;* and *Lituites cornu-arietis*—are the highest forms of life known here.

Products—inferior slates; flagstones; metallic ores in veins.

Period 3.—**Silurian** (Upper Silurian of Murchison).

Including (*a*) Llandovery or Pentamerus beds (Valentian); (*b*) Wenlock (Salopian) beds; and (*c*) Ludlow (Clunian) beds.

N.B.—Abundance of Corals and Encrinites; and the Trilobites *Phacops caudatus; Calymene Blumenbachii, Homalonotus.* Advent of Vertebrates (Ganoid Fishes), Scorpions and Insects.

Graptolites, chiefly *Monograptus* and *Rastrites*, still abound, though rare in the Ludlow beds where ganoid fishes first occur—*Pteraspis, Plectrodus; Cephalaspis.* Corals, chiefly rugose, increase to 80 species (mostly in the limestones)—*Cyathophyllum truncatum, Omphyma turbinata; Acervularia; Heliolites; Favosites,* and the chain coral *Halysites catenulatus.* Crinoids (55 sp.)—*Actinocrinus, Cyathocrinus.* Starfishes (*Protaster, Palaeaster*) and coral-like Polyzoans increase, while Trilobites decrease (to 130 sp.)—*Phacops; Calymene, Homalonotus delphinocephalus.* Brachiopods are very abundant and varied (126 sp.)—*Atrypa reticularis, hemisphaerica; Rhynchonella Wilsoni, Salteri, navicula; Orthis reversa, rustica, lunata; Strophomena depressa, euglypha; Spirifer plicatellus; Pentamerus lens* and *P. oblongus* in Llandovery; *P. galeatus* in Wenlock; *P. Knightii* in Ludlow beds.

The Gasteropods *Euomphalus discors, Bellerophon dilatatus;* and the Cephalopods *Orthoceras annulatum, bullatum, Ludense, &c.,* are typical. In the newest beds occur (at Rumney, May Hill, &c.) twigs of land plants and the supposed

America a supposed huge Alga, *Prototaxites*, occurs in Silurian strata.

Products—of but little value—flagstones, sandstones, lime.

Period 4.—**Devonian** and **Old Red Sandstone**.

"The Age of Ganoid Fishes and Eurypterids."

The marine fauna (only 400 species described against 1,500 Silurian species) is very widely spread, but in Britain is confined to the slates and limestones of the south-western counties.*

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* Marine Devonian rocks occur beneath London and Essex, and probably extend from Somerset under the Cretaceous rocks of south-east England and Belgium, rising to the surface in the Ardennes, Eifel, and Coblentz districts.

Fishes (in the marl-slate and copper shales); Labyrinthodonts—*Branchiosaurus; Lepidotosaurus;* and a true reptile (lizard) *Proterosaurus.*

Products—Magnesian limestone and sandstones for building; gypsum; and in Germany also rock salt and copper.

II.—THE MESOZOIC OR SECONDARY PERIODS.

"The Era of Cycads, Saurians and Marsupials."

Like the Lower and Upper Palæozoic so the Mesozoic series contains three successive faunas. Hence three Periods and Systems are distinguished.

Of nearly 6,000 Palæozoic species known, none, or but a few lowly forms, are found in newer rocks, though many genera still survive (see p 83)

Period 7.—**Triassic** (*a*) Bunter, (*b*) [Muschelkalk], (*c*) Keuper.

N.B.—The Lily Encrinite; Labyrinthodonts; *Ceratites;* Cycads.

The small bivalve Crustacean, *Estheria minuta.*

The Advent of Mammals—the marsupial *Microlestes.*

In the Eastern Alps the marine Triassic fauna is best seen, Cephalopods being especially numerous. *Ammonites* and *Belemnites* occur with *Goniatites* and *Orthoceras;* and *Turritella* and *Nerinæa* (Gasteropods) with *Murchisonia* and *Euomphalus*

In the marine shelly limestone or Muschelkalk of Germany occurs *Encrinus liliiformis*, the stone lily, *Nautilus bidorsatus*, *Ceratites nodosus.*

In the lacustrine beds (New Red Marls and Sandstone) of Britain and Germany occur—though but rarely

Plants—many Ferns, *Equisetum columnare*, a true horse-tail; *Pterophyllum; Zamites* and other Cycads, the conifers *Voltzia heterophylla*, *Albertia.*

Fishes—teeth, &c, of *Acrodus*, *Ceratodus*, *Hybodus major, H. Keuperi.*

Amphibia—*Labyrinthodon*, *Mastodonsaurus.*

Reptiles—*Telerpeton Elginense; Rhynchosaurus; Thecodontosaurus*

In the Rhætic or Penarth passage beds occurs a thin "bone-bed with fish scales, teeth, and bones, and with Saurian bones and coprolites (droppings) Above this are shales often full of the Lamellibranch bivalves *Avicula contorta; Cardium Rhæticum, Pecten Valoniensis* In the succeeding White Lias are limestone bands equally crammed with shells of *Ostrea Liassica; Modiola minima; Monotis decussata.*

This group of many thin strata so full of remains of shallow-water life (125 sp.) points to a period of slow climatic and geographical change, the depression of the arid Permian and Triassic continent with many salt lakes, and the creeping over it of the open sea in which the Jurassic series was deposited later.

Products—Sandstones for building and paving; gypsum for "Plaster of Paris" and alabaster; rock salt and brine for salt.

Period 8.—**Jurassic**, including **Oolitic** and **Liassic**.

"The Age of Cycads, Ammonites, and Reptiles,"

Remarkable for the great variety and abundance of life, almost every class of animals and plants being well represented in it. The marine forms are a great contrast to those of the last marine period, the Carboniferous. Its fauna and flora have many analogies with those now living in Australia, where many Jurassic types still survive, *e.g.*, marsupial mammals, *Trigonia*, Cycads.

Sub-tropical plants: Ferns (*Pecopteris*, *Glossopteris*),

Equisetums, Cycads (*Cycadites*, *Pterophyllum*, *Mantellia*).

Conifers (*Pinites*, *Thuytes*) abounded, and in Yorkshire have formed thin coals and jet.

Corals (*Isastraea*, *Thamnastraea*, *Thecosmilia*) and Encrinites (*Pentacrinus*) largely form many limestones. Sea-urchins (*Cidaris*, *Hemicidaris*, *Clypeus*), and

Brachiopods (*Terebratula*, *Rhynchonella*) swarmed, as also

Oysters (*Ostrea*, *Exogyra*, *Gryphaea*) and allied shells (*Lima*, *Pecten*, *Pinna*, *Trigonia*, *Cardium* or cockle).

The most striking feature throughout the marine beds is the abundance and great variety of the chambered shells of Cephalopods (*Ammonites*, *Nautilus*) and the guards ("thunderbolts") of the allied cuttle-fish *Belemnites*, and which serve to mark off the formations into zones, each marked by a particular species, since the vertical range of each is small.

Fishes, mostly small ganoid and shark, abounded, and Reptiles became extraordinarily developed. They haunted the coasts (*Ichthyosaurus*, *Plesiosaurus*, *Pliosaurus*), the rivers (*Teleosaurus*, and their crocodile), flew through the air, the dragon-like flying Lizard or Pterodactyl, while others of colossal size and strength (Dinosaurs) roamed over the land, *Iguanodon*, *Cetiosaurus*, *Megalosaurus*, and in America [illegible], *Atlantosaurus* (see p. 68). These creatures seemed to have reached the limits of their dominion toward the close of the period. Their numbers and the variety of their modification are quite extraordinary. Not only did they swarm in the seas and rivers, but they peopled the land with giant herbivores, and filled the air with winged forms. They thus adapted themselves for all kinds of food and all conditions of life with an elasticity of organization which is truly remarkable. (Jukes-Browne.)

The earliest known Bird (*Archaeopteryx*), having reptile-like teeth, tails and fore-claws, occurs in the Upper Oolite of Bavaria.

Mammals—lower jaws and teeth of small marsupials occur but at two horizons only, in the Stonesfield Slates and Purbeck Beds (which see).

Liassic fossils (1800 sp.) include *Gryphaea incurva*, *Lima gigantea*, *Ammonites* (130 sp.), *Nautilus*, *Belemnites* (60 sp.). See pp. 8, 9, for zones marked by species of Ammonites.

Pentacrinus Briareus, [illegible], *Rhynchonella tetrahedra*, *Spiriferina Walcotti*, [illegible], *Cardinia*, teeth of fishes (*Acrodus*, *Hybodus*), and skeletons of the huge sea-lizards *Ichthyosaurus communis*, *Plesiosaurus macrocephalus*.

In the passage bed, Midford Sands or Supra-Liassic Sands, including the Cephalopoda bed, occurs *Rhynchonella cynocephala*, *Ammonites variabilis*, &

Inferior Oolite (Bajocian) with *Ostrea flabelloides*, *Trigonia*; *Terebratula fimbria*, *simplex*, *plicata*, *Rhynchonella spinosa*, *concinna*. *Pholadomya fidicula*. Ech. *Clypeus*.

The zones of *Ammonites Murchisonae*, *Sowerbyi*, *Humphriesianus*, *Parkinsoni* (at top); also Belemnites giganteus, *Trigonia costata*, and the Gast. *Pleurotomaria* [illegible]. In Yorkshire occur (in clays, shales and coal) land plants and freshwater shells.

Fuller's Earth with *Ostrea acuminata*, *Rhynchonella concinna*, *varians*, *Terebratula ornithocephala*.

Great Oolite with *Ostrea Sowerbyi*, *Trigonia Goldfussii*, *impressa*, *Lima cardiiformis*, *Terebratula digona*, *maxillata*.

In the Stonesfield slate, thin bedded limestones below the freestone and lying east of Cheltenham, occur jaws of land mammals (*Amphitherium*, *Phascolotherium*, *Stereognathus*), also flying reptiles (*Rhamphocephalus*) and insects.

Forest Marble full of oysters, Encrinites and *Avicula costata*.

In the Bradford clay of Wilts below, the [illegible] abounds ([illegible]) and [illegible].

Cornbrash, a rubbly limestone with *Terebratula lagenalis*, *Ammonites discus*, *Am. Herveyi*, and many Echinoderms.

[illegible]

Oxford Clay (Oxfordian) with *Gryphaea dilatata*, [illegible], and many Cephalopods, *Ammonites* and *Belemnites*.

[illegible]

Coral Rag (Corallian) full of Corals, [illegible] *explanata*, [illegible]

[illegible]

Kimeridge Clay with *Ostrea deltoidea*, *Gryphaea virgula*.

These two oysters [illegible] very characteristic.

Portland Beds with *Cardium dissimile*, *Cyprina rugosa*, *Trigonia*, *Lima*, *Cerithium Portlandicum* (screws).

The oysters and other mollusc shells occur (in the limestone) mostly as internal casts or as moulds (pseudomorphs in silica, chert).

Am. giganteus 3 or 4 feet across. [illegible] *Pecten lamellosus*. *Isastraea oblonga*, a coral (usually silicified).

Purbeck Beds with terrestrial and fresh-water fossils, and *Ostrea distorta* forming the "cinder-beds."

Plants chiefly in the "Dirt-beds" (old soil)—Silicified stems of Conifers *Pinites*; and of Cycads *Mantellia nidiformis*; also *Chara* fruits.

Crustaceans—Valves of *Cypris*; *Cypridea*. Lam.: *Cyrena elongata*; Gast.: the fresh-water snails *Planorbis*; *Physa*: *Limnæa*; *Paludina carinifera* forming Purbeck marble

Fish—*Lepidotus*; crocodiles and turtles; and 24 species of marsupial mammals—*Plagiaulax*, *Triconodon*; *Stylodon*; *Spalacotherium*.

Products of Jurassic strata—Purbeck and Forest marbles. Bath Oolite and other freestones for building; flagstones for roofing, paving; ragstones for lime and road-metal: thin coals and jet; bituminous shales for fuel, oil, tar: clay ironstone (Cleveland ore) and iron-sands (Northampton sands); fuller's earth.

Period 9.—**Cretaceous.**

"The Age of Iguanodon, Mosasaurus, Hippurites."

The mammals are unknown; birds occur, *Enaliornis* (or ***Pelagornis***); sharks abound, *Ptychodus*; *Otodus*; but the most striking vertebrate forms are huge land saurians, *Iguanodon*; sea-lizards, *Ichthyosaurus*; sea-serpents, *Mosasaurus* (? 75 ft. long); and flying *Pterodactyls* of great size. Among mollusca, *Belemnites* and the Ammonitilian forms, *Ammonites*; *Hamites*; *Scaphites*; *Turrilites*: *Baculites*; *Crioceras*; *Ancyloceras*, are very abundant, but here die out. Of Lam.: *Hippurites* (forming thick limestones in S. Europe) are confined to rocks of this Period: *Inoceramus*: *Pecten*; *Ostrea* and *Exogyra* (*Gryphæa*) are common; as are Echinoderms *Ananchytes*: *Micraster*.

The Lower Cretaceous or Neocomian life (of 280 sp. mostly land, fresh-water, or shallow-sea forms) much resembles that of the Jurassic—Cephalopods, Saurians, Conifers and Cycads.

The Upper Cretaceous life, as seen in British strata, is markedly different, as the Cretaceous sea greatly extended its area to the north and west as the period progressed and England sank. This caused the upper series to overlap unconformably the lower series, or still older beds, the Oolite, Lias, and even Trias. In this Cretaceous ocean, Foraminifera (of 100 sp. *Globigerina*, *Rotalia*) accumulated over Western Europe, forming the great bulk of chalk; coral-reefs do not occur. The abundant sponges, *Siphonia*; *Ventriculites*, formed the nuclei of many flint nodules, or afforded much of the silica which collected round other bodies, or replaced their lime, so forming flints (see p. 44), bands of nodules of which are so characteristic of the Upper Chalk.

(a) The fresh-water **Wealden** strata, a vast delta deposit, contains abundant plant remains, *Endogenites erosa*: *Equisetites Lyellii*; *Lonchopteris Mantellii*, minute crustacean bivalves, *Cypridea*, *Cythere*; Lam., *Unio valdensis*; *Cyclas*; *Cyrena media*, *parva*; Gast., *Paludina fluviorum* (forming Sussex marble), Fish, *Lepidotus Mantellii*; and huge saurian reptiles.

(*b*) The marine Atherfield clay shows the incoming of the sea, and the succeeding **Lower Greensand** is marine, with *Terebratula sella*; *Perna Mulleti*; *Gryphæa sinuata*; *Ammonites Deshayesii*, *Martini*.

(*c*) **Gault** with Corals, *Cyclocyathus*; Crinoids, *Pentacrinus*; Crabs, *Palæocorystes*; Lam., *Inoceramus concentricus*, *sulcatus*; *Plicatula*, *Nucula*; Gast., *Natica gaultina*; *Aporrhais*, *Turritella*; Ceph., *Am. interruptus*, *lautus*, *splendens*, *rostratus*; *Hamites intermedius*, *Belemnites minimus*.

(*d*) **Upper Greensand** with Sponges *Siphonia*; *Jerea*; Lam., *Pecten asper*, *quinquecostatus*, *quadricostatus*; and Ech., *Diadema*; *Salenia*.

(*e*) **Lower Chalk** and **Chalk Marl** with Ceph., *Scaphites æqualis*; *Turrilites costatus*, *Am. Rothomagensis*, *varians*; Lam., *Inoceramus latus*.

(*f*) **Upper** and **Middle Chalk** with Ech., *Ananchytes ovatus*, *Galerites conicus*; *Micraster cor-anguinum*, *cor-bovis*; *Holaster planus*; *Cyphosoma*. Lam., *Inoceramus mytiloides*; *I. Cuvieri*. In the highest beds found at Gravesend and in Norfolk, occurs *Belemnitella mucronata*.

Products—Chalk for lime, cement, whiting; flint for walls, oad-metal, china making; Kentish rag, Totternhoe stone, &c., or building; Coprolites for manure (see p. 22); iron pyrites.

III.—THE CÆNOZOIC OR TERTIARY PERIODS.

"The Era of Birds, Mammals and Dicotyledons."

NOTE.—A great palæontological break occurs in Europe between the ocean formed chalk and the shallow-water (often estuarine and fresh water) Tertiary deposits, though unconformity of the strata is rarely apparent. This great change in fossils denotes greatly changed conditions, but not necessarily a vast interval of time as was long supposed. In North America, Syria, and Egypt, passage beds bridge this gap. Here all the great Saurian reptiles, the Ammonitidian forms, the genera *Belemnites*, *Inoceramus*, *Gryphæa*, &c., disappear, and in their place come a great variety of non marsupial forms of mammals, new genera of Molluscs, *Murex*, *Melania*, &c.; *Cypræa*, *Pyrula*, *Pleurotoma*, *Voluta*, *Conus*.

Period 10.—**Eocene**, with *Nummulites*, *Turritella*, *Pleurotoma*, *Voluta*, *Conus*, *Nautilus*; teeth of sharks, *Lamna*, *Otodus*, *Carcharodon*; and sub-tropical plants.

(*a*) In the Lower London Tertiaries occur, in the marine **Thanet Beds**, Lam., *Cyprina Morrisii*; *Cardium Laytoni*, in the estuarine **Woolwich Beds**, Lam., *Ostrea tenera*, *bellovacina*; *Cyrena cuneiformis*, *cordata*. Gast., *Melania inquinata*, *Cerithium funatum*, *Paludina lenta*; in the fresh water **Reading Beds** are plant remains only.

(*b*) In the marine **London Clay** occurs in the sandy basement bed and the shore-formed **Oldhaven Bed**, *Aporrhais Sowerbyi*, *Cardium Laytoni*; *Ditrupa plana* (stony worm-cases); and in the clays above, especially at Sheppey, occur plants—leaves and fruits of Palms (*Nipadites*), Screw-pines, Pines, Laurels, Figs; also borings in fossil-wood by *Teredo*; Lam., *Panopæa*; Gast., *Turritella*. Ceph., *Nautilus imperialis*, *centralis*, *zic-zac* (*Aturia*); also Fish (of 60 sp.), the Sea-snake *Palæophis*; Turtles; Crocodiles; and Birds, *Odontopteryx*, *Lithornis*.

(*c*) In the marine **Bracklesham Beds** and **Middle Bagshot Beds** are *Nummulites lævigatus*; Lam., *Cardita planicosta*; *Chama squamosa*; Gast., *Cerithium giganteum*. In the **Bournemouth Beds** and **Bovey Beds** (f.w.) are a great variety of plant leaves.

(*d*) In the marine **Barton Beds** and **Upper Bagshot Beds** occur many Gasteropod shells, *Voluta athleta, luctatrix*; *Conus*; *Oliva*; *Pleurotoma*.

Products—Sands for mortar, glass-making; lignite; pipe-clay.

Period 11.—**Oligocene** (or Upper Eocene and Lower Miocene.) The Fluviomarine series of Hants and Isle of Wight.

(*a*) Headon Beds. (*b*) Bembridge Beds. (*c*) Hamstead (or Hempstead) Beds.

In the marine Middle Headon Beds are Corals, Lam., *Cytherea* (*Venus incrassata*, Gast., *Voluta spinosa*; and in the U. Hamstead Beds, *Corbula pisum, vectensis* abound, forming "Corbula Beds."

In the other beds (brackish and fresh-water) are Lam., *Ostrea ventilabrum*; *Cyrena pulchra, obovata, semistriata*; *Unio Solandri*; Gast., *Paludina lenta*; *Planorbis lens*; *Limnæa longiscata*; *Melania*; *Potamides*; also land-shells, *Helix*; *Clausilia*; stems and seeds of *Chara* (f.w.), and land plants.

Mammals of many greatly differing genera, particularly of Ungulates, occur, and especially in North Germany and France (50 sp. in the gypsum of Montmartre, Paris, alone), *Palæotherium*, *Anoplotherium*; and the probable ancestors of existing deer (*Xiphodon*), hog (*Hyopotamus*), horse (*Anchitherium*), and rhinoceros.

Products—Sand for glass-making, pipe clay: [amber, gypsum].

N.B.—During this and the next Period the Alps and Pyrenees rose into mountain chains, and volcanic eruptions on a grand scale took place in Auvergne and Bohemia during their upheaval; while somewhat earlier still grander volcanoes were in eruption in Britain, Skye, Mull, and Antrim. In Switzerland, the "molasse" series was deposited, including the Rigi conglomerate (nagelflue) 6,000 feet thick

Period 12.—**Miocene.**—"The Age of Dinotherium."

Miocene lake deposits cover large areas in Central France (Auvergne), Switzerland (the Œningen Beds so rich in fossils), Germany; and marine deposits extend from the Alps north to Mainz, east to the Carpathians. Rich Floras occur in Greenland and Spitzbergen. No deposits are known in Britain.

Huge Proboscidean mammals, *Dinotherium* and *Mastodon*, here occur; also true Apes, an Ass (*Hipparion*), Giraffe, and very abundant insect life. In the Sewalik Hills of N. India occur elephants (of 6 sp.): *Mastodon*; *Sivatherium*, a huge four-horned antelope.

Period 13.—**Pliocene,** with the Crag deposits.

The numbers after the names of the formations refer to the approximate percentage of the molluscan species still living (*a*) **Coralline Crag** (84) with coral-like Polyzoans (of 140 sp.), *Eschara*; *Fascicularia*; Brach., *Terebratula grandis*.

Lam., *Astarte Omalii*; *Cardita senilis*; *Pecten opercularis*; Gast., *Voluta Lamberti*; Mam., whales, *Balæna*; *Balænodon*. Derived forms, chiefly in the Coprolite Beds, sharks and rays, *Carcharodon*; *Otodus*; *Raia antiqua*.

The Lenham Beds capping the North Downs, and the St. Erth Beds of Cornwall, are of this or the succeeding Red Crag age.

(*b*) **Red Crag** (90) with the reversed whelk *Trophon antiquus* (*Fusus contrarius*), *Purpura tetragona*, *Cardium edule*.

Of the White Crag species 140 lived also into the Red Crag age, and many Red Crag fossils are derived from the debris of White Crag and London Clay by their denudation.

Lam., *Astarte obliquata*; *Pectunculus glycimeris*; *Mactra ovalis*; Gast., *Natica*; *Scalaria*, and various whelks, *Buccinum*; *Fusus*; *Purpura*; *Nassa reticosa*.

In the Coprolite Beds are bones and teeth of *Mastodon*, whales, sharks and rays, with phosphatic nodules; the whole now often ground for manure.

(*c*) **Norwich Crag** (94) with *Mastodon arvernensis*: Lam., *Astarte borealis*; *Nucula cobboldiæ*: the common cockle, *Cardium edule*.

The terms "Fluviomarine Crag" and "Mammaliferous Crag" well describe this deposit; the mammals include Elephants (?), Mastodon, Horse, Hippopotamus.

(*d*) **Forest Bed** of Cromer, with an extensive Flora and mammalian Fauna.—Elephants, Rhinoceros *R. etruscus*, Horse.

The plants are mostly of existing British species—water-lily, and other water plants, sloe, elm, oak, beech, fir, yew, rush. The trees have been drifted and settled as "snags" in rivers. The mammals include *Elephas antiquus* and *E. meridionalis*, and many forms of deer (*Cervus Sedgwickii*), also a beaver, *Trogontherium*, all now extinct, as well as *Cervus elaphus* and many smaller mammals of species still living.

THE QUATERNARY OR POST-TERTIARY PERIODS.

"The Era of the Irish Elk, Mammoth, and Man."

The Quaternary deposits are of all kinds—marine, estuarine, fluviatile, lacustrine, glacial, subaerial, and terrestrial. They cover large areas in Britain and rest indifferently on all older rocks. They are hence termed Superficial or Drift deposits. The older ones are mostly due to attrition and often carriage by ice (Glacial), and consist of unstratified Boulder clay, contorted gravels and sands (pp. 4-5). Derived fossils are of course common, especially stout forms like *Belemnites*, *Gryphæa*.

Plateau or "Cannon-shot" gravel is mostly of Upper Glacial age, as is much of the Diluvial or Torrential deposits (flood-gravels) found at higher levels in the Thames and other valleys; while the low-level gravels and alluvial deposits are post-glacial and mostly recent, as are most soils, river-flats, shingle-beaches (see p. 5).

Period 14.—**Pleistocene,** with the Glacial deposits.

"The Age of Ice-sheets, Great Glaciers, and Icebergs."

This period is by many authors made to include all Recent deposits, as no clear line of separation can be drawn. Some authors group all the deposits, from Miocene to Recent inclusive, into a single system, the Icenian.

The mollusca are all of still living species, but of the mammals many are extinct, and others now live only in distant and widely remote parts of the earth; arctic, temperate and tropical forms being mingled. Their remains occur with rough flint implements of Early Prehistoric or Palæolithic man—"river-drift and cave man."

These mammals include the hairy Mammoth *Elephas primigenius*, also *E. antiquus*; the woolly Rhinoceros *R. tichorhinus*; *Hippopotamus*; *Hyæna*, Lynx, Cave Lion, Cave Bear, Boar, Bison, Beaver, Musk Ox, Reindeer, and the Bighorn Deer or Irish Elk *Cervus megaceros*

In N. America occur most of the above, also a Mastodon, *M. Ohioticus*.

In S. America occur gigantic progenitors of living species now peculiar to it, the huge ground sloth *Megatherium*; *Megalonyx*; *Mylodon*; and the giant armadillo, *Glyptodon*.

In Australia occur gigantic kangaroos, *Diprotodon*, and wombats

In British glacial deposits occur Lam., *Unio littoralis*; *Corbicula* (*Cyrena*) *fluminalis* (f.w.) now extinct here, also *Pecten islandicus*, *Cyprina islandica*, *Leda truncata*, *lanceolata*, *Tellina Balthica*, *lata*, *Astarte borealis*; and Gast., *Turritella terebra*, *Natica clausa*, all now nearly confined to northern seas

Period 15.—**Recent**—Later Prehistoric and Historic.

"The Ages of Iron, of Bronze, and of Polished Stone Implements."

The Recent Formations are those accumulated since the establishment of the present general arrangement of land and sea, the present distribution of climate, and of the existing floras and faunas, and are marked by the occurrence of Neolithic and later works of man—weapons, ornaments, tools, tombs, dwellings, together with his bones: also heaps of kitchen refuse or shell-mounds (the Danish Kjoken modding), and of charred wood; and the remains of domestic animals.

RANGE IN TIME OF CHIEF FOSSILS.

See also p. 16, pp. 63-69, and Special Notes on Trilobites, Brachiopods, Cephalopods, pp. 69, 70.

All the classes of Cryptogamic or Flowerless Plants range from Palæozoic to Present, but attained their maximum in size and numbers in the Carboniferous. All Pre-Tertiary Algæ and Fungi are doubtful

Conifers range from Devonian, and Cycads from Permian to Present.

Monocotyledons have not as yet been recognised *with certainty* in pre-Jurassic strata. [*Pothocites*, a supposed Aroid from the Coal measures, is now set down as a *Sigillaria*: and various leaves of the same age termed *Palmacites*, *Yuccites*, are of too doubtful a nature.] *Podocarya* from Inf. Oolite, the fruit of a Pandanaceous tree, is the earliest known.

Dicotyledons range from U. Cretaceous strata at Aachen, also in Greenland and Dakota; but in Britain from the Reading Beds (Lower Eocene).

All the classes of Invertebrate Animals, whose remains can be preserved in recognisable forms, range from Palæozoic to Present, though many sub-divisions of the classes (families or orders) did not survive Palæozoic times. (See p. 16).

Of Vertebrates, three classes date back from Palæozoic and two from Mesozoic, all still existing.

Of Fishes, Ganoids and Elasmobranchs date from Silurian (L. Ludlow) *Pteraspis*; and Teleostean or bony fishes, with certainty from the Cretaceous only; the spiny-finned *Beryx* still existing.

Of Amphibians, the Labyrinthodonts date from the Carboniferous *Archegosaurus*. Other forms, *e.g.*, frogs, salamanders, from the Miocene.

Reptiles date from the lizard-like *Protorosaurus* of Permian age.

Birds date from the U. Oolitic *Archæopteryx*, and in Britain the *Enaliornis* of Cretaceous age. Supposed footprints occur in Sandstone. Conn. Triassic.

Of Mammals, marsupial forms date from the Triassic *Microlestes*; *Tritylodon* (of S. Africa) and *Dromatherium* (of N. Carolina), but undoubted non-marsupial forms do not occur before Eocene times, *Palæotherium*.

The following important genera are distributed in time thus: I., Palæozoic; II., Mesozoic; III., Cænozoic.

CONFINED TO I.—All the genera of Graptolites, Rugose Corals, Cystoid and Blastoid Echinoderms, Crust., Trilobites (p. 69), also *Eurypterus* and *Pterygotus*; Brach. (p. 70 and XVI.), *Atrypa*, *Orthis*, *Pentamerus*, *Productus*, *Spirifera*, *Strophomena*, Lam., *Ctenodonta* (30 sp.) from Tremadoc to Coal M., *Palæarca* Tremadoc to Ludlow, Gast., *Euomphalus* and *Murchisonia* from L. Silurian, *Bellerophon* from Cambrian, Ceph., *Orthoceras* from U. Cambrian, *Goniatites* from Devonian; the last five ranging up into the Alpine Trias, but in Britain into Carboniferous only.

IN I. AND II.—Labyrinthodont family, but no genera.

IN I., II. AND III. still living.—Brach., *Lingula* from Camb., *Rhynchonella* from U. Sil., *Terebratula* from Dev., Lam., *Anodon*, *Pinna*, from Dev., *Arca* and *Avicula* from L. Sil., *Mytilus* (mussel), *Nucula* from Perm. (or Silurian). Gast., *Pleurotomaria* (1,150 sp.) from Sil., *Trochus*, *Turbo* from L. Sil., *Natica*, *Patella* from Carb., Ceph., *Nautilus* from Silurian (in Britain, from Devonian).

CONFINED TO II.—From Trias to Chalk. *Ammonites*, *Belemnites*; *Plesiosaurus*, *Ichthyosaurus*; *Acrodus*, *Hybodus* (fish). From Lias to Chalk.—*Pterodactyls*, *Nerinæa*, *Gryphæa*, *Inoceramus*. In Cretaceous only, *Marsupites*, *Hippurites*, *Radiolites*; also *Iguanodon*, *Hamites*, &c. (p. 70).

IN II. AND III.—From Trias to Present.—Ech., *Cidaris*, *Pentacrinus*, Lam., *Cardium*, *Cardinia*, *Cardita*, *Lima*, *Ostrea*, *Unio*, Gast., *Turritella*. Fish, *Ceratodus*. From Lias to Present.—Lam., *Trigonia*, *Pholadomya*, *Astarte*, Gast., *Cerithium*. From Purbeck (fresh-water), *Cyclas*, *Cyrena*. Gast., *Paludina*. From Neocomian, Lam., *Pectunculus*; Gast., *Aporrhais*. From Chalk, *Beryx* (fish).

CONFINED TO III., but now extinct.—*Nummulites* in Eocene only. Among Mammals, the huge forms *Dinotherium*, *Mastodon*, Mammoth; *Sivatherium*, Irish Elk, &c., as well as many species which were probably the ancestors of the existing Eutherian Mammalia.

ADDITIONAL NOTE ON MINERALS.

Macroscopic characters readily observed.

Quartz glassy; scratches steel and glass; no cleavage; crystals 6-sided.

Chalcedony similar, but not in crystals, and often banded, as in *Agate*.

Felspars scarcely scratch glass and not steel; distinct cleavage-faces giving a step-like structure, opaque, shining white or pale red; crystals brick-like.

Mica cleaves readily into smooth very elastic flakes; of any colour.—H. 2—3.

Talc, white or green, opaque; very soft, H. 1; feels greasy; cleaves well.

French Chalk, *Soapstone* are similar, being massive forms of Talc.

Serpentine feels greasy; takes good polish, stained dark red and green.

Selenite transparent; soft. H. 2, easily cleaves into flexible inelastic flakes.

Gypsum translucent; fibrous or granular; easily cut, H. 2

Hornblende and *Augite* black (greenish); heavy, cleaves; often corroded.

Schorl black; striated; conchoidal fracture; not scratched by steel.

Calcite easily scratched by steel, effervesces freely with acid; more or less transparent; strongly doubly refractive; crystal faces mostly rhombs.

Dolomite less soft; effervesces slowly unless in powder or the acid be warm.

Halite (*Rock Salt*) tastes of salt; easily cut by a knife; H. 2; often iron-stained.

Kaolin soft, plastic if wet, earthy odour when breathed on.

Graphite soft; shining black; greasy feel; gives a black streak on paper.

Magnetite heavy; black; attracted by magnet, gives a black streak.

Hæmatite heavy; red to black; gives a blood red powder and streak.

Limonite brown, yellow black; gives a brown or yellow powder and streak.

Iron Pyrites very hard and heavy; brassy lustre; in cubes or rounded nodules.

Copper Pyrites can be cut by knife; redder than last; far rarer.

Galena very heavy; lead-like lustre; very brittle; cleaves easily.

Microscopic characters of thin sections viewed by transmitted light with low-power objective.

I.—**Opaque,** and hence seen *black*—Magnetite, Hæmatite, Limonite, Pyrite, Titanoferrite (all compounds of Iron).

II.—**Coloured**—Felspars when stained by Iron, *grey*, *red* or *brown* (Muscovite, *faint yellow*); Biotite, Augite, Hornblende, *green*, *yellow* or *brown*, Serpentine, *green* in patches and streaks; Garnet, *pale pink*, in rounded forms.

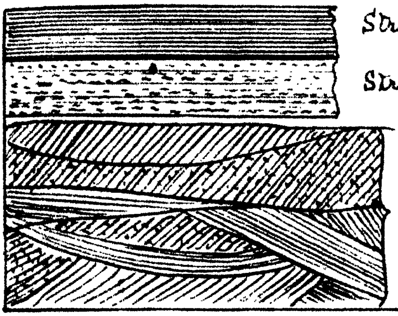
III.—**Dichroic**—Use polariser only, which rotate The following change their tint—Biotite, Hornblende, Tourmaline, *strongly*; Augite, Chlorite, Muscovite, Serpentine, *faintly*.

IV.—**Polarising** in colours—Use analyser and polariser, rotate latter. The following, when undecomposed, show changing, often vivid colours—Quartz, Hornblende, Augite, Olivine, Nepheline, Natrolite, Felspars (Orthoclase shows simple twinning, Plagioclase repeated twinning, and consequently narrow bands of colour), in fainter tints—Muscovite.

V.—**Isotropic**—Cross analyser and polariser so as to get a dark field, then rotate the stage with rock section The following remain dark, since they are not doubly refractive (and they do not polarise)—Glassy matter, crystals of the Cubic System, *e.g.*, Garnets, Nosean, and crystals of the Tetragonal and Hexagonal systems when cut at right angles to their vertical axis.

END.

Relating to Stratification.



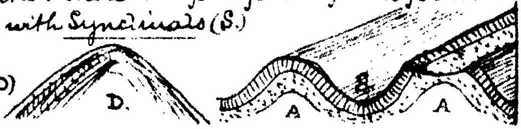
Stratum of clay. Stratum of Sand } showing regular lamination

Strata of clay or sand deposited in shallow water, showing Irregular and oblique lamination, or Current Bedding.

Strata may be horizontal, or be variously inclined, even to being vertical; or they may be actually inverted. These latter positions are due to folding of the originally horizontal strata. There are four forms of such folds:— Anticlinals (A) with Synclinals (S.)

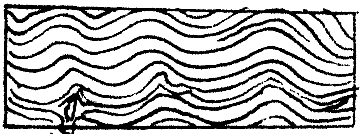
Periclinals or **Domes** (D)

Centroclinals or **Basins**—reversed Domes.

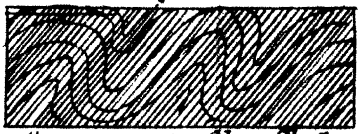


Subsequent denudation produces the surface arrangements of the strata seen on pages VI to IX.

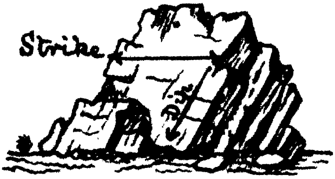
The pressure which produces the folding may cause crumpling or Contortion, or even a Cleavage structure.



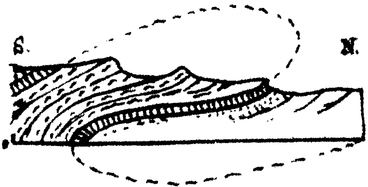
Contorted strata



Cleavage in Clay Slate.

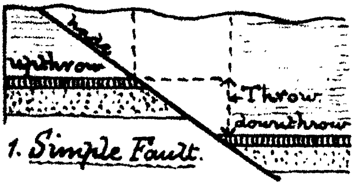


Dip and Strike.

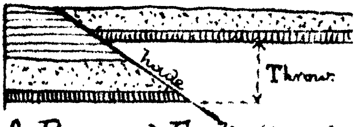


Inversion of Strata.
in Jura Mts.

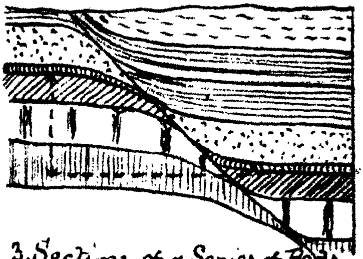
Faults or Dislocations of strata.



1. Simple Fault.

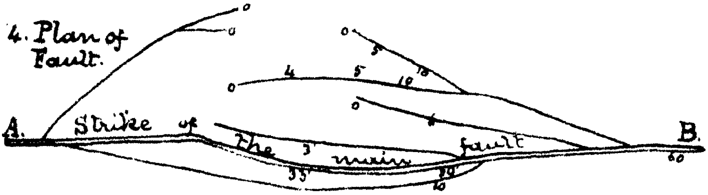


2. Reversed Fault. (rare)

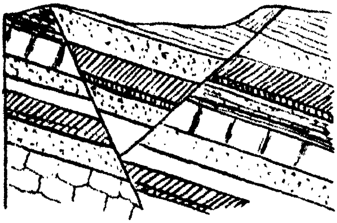


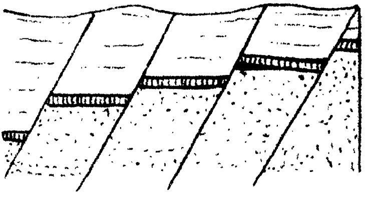
3. Section of a Series of Beds distorted by a Fault. (the usual result)

4. Plan of Fault.



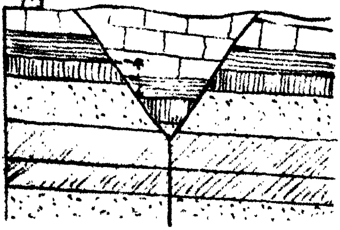
Ground Plan of a main Fault, AB. with its branches and parallel faults. The figures show the throw in feet, and are placed on the downthrow side.

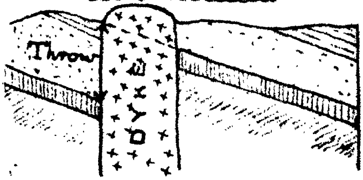




5.} Trough Faults.
7.

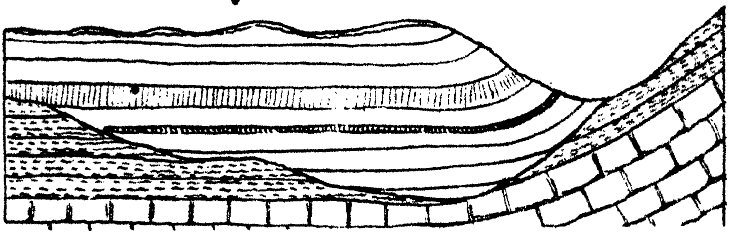
6. Step Faults.





8. A Dyke Fault.

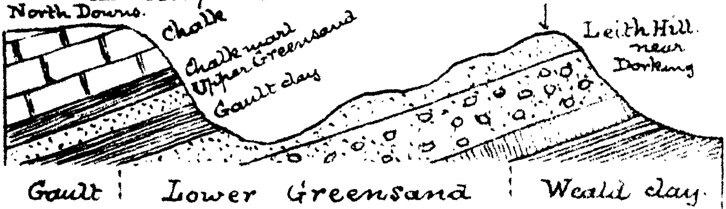
Unconformable Strata.



Case of Unconformity without change of Dip, showing also Overlap by each bed of the upper series of the bed next below it.

For cases of Unconformity with change of Dip see pages VIII.

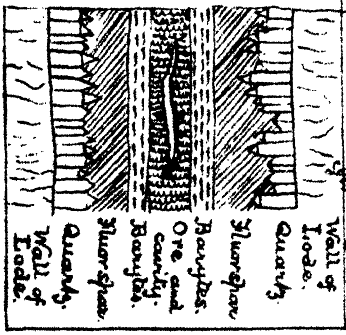
Escarpment and Outlier.



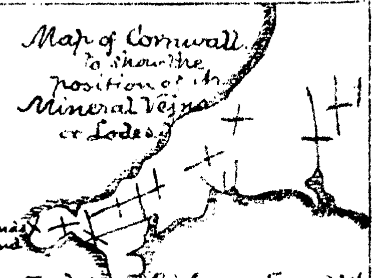
Note. – The dip of strata and slopes of surface are too great.

For an Inlier see The Weald on pages V. VI.

Section across a Lode.



Map of Cornwall to show the position of the Mineral Veins or Lodes.



The lodes which run E. and W. contain Copper and Tin chiefly; those which run nearly N. & S. yield Lead and Iron chiefly.

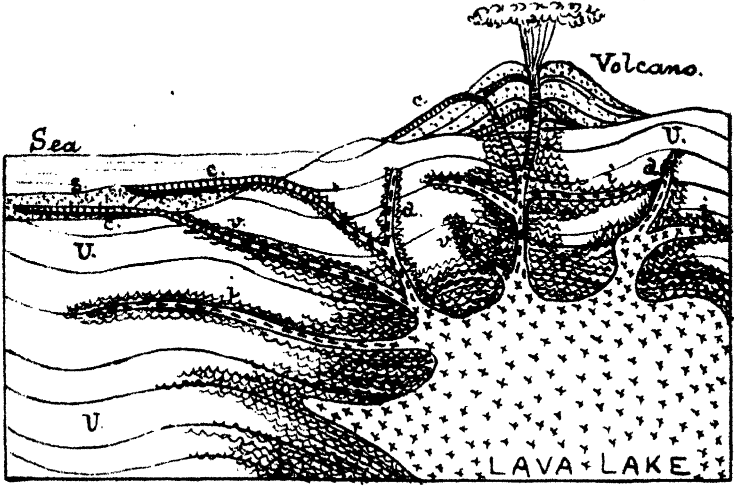
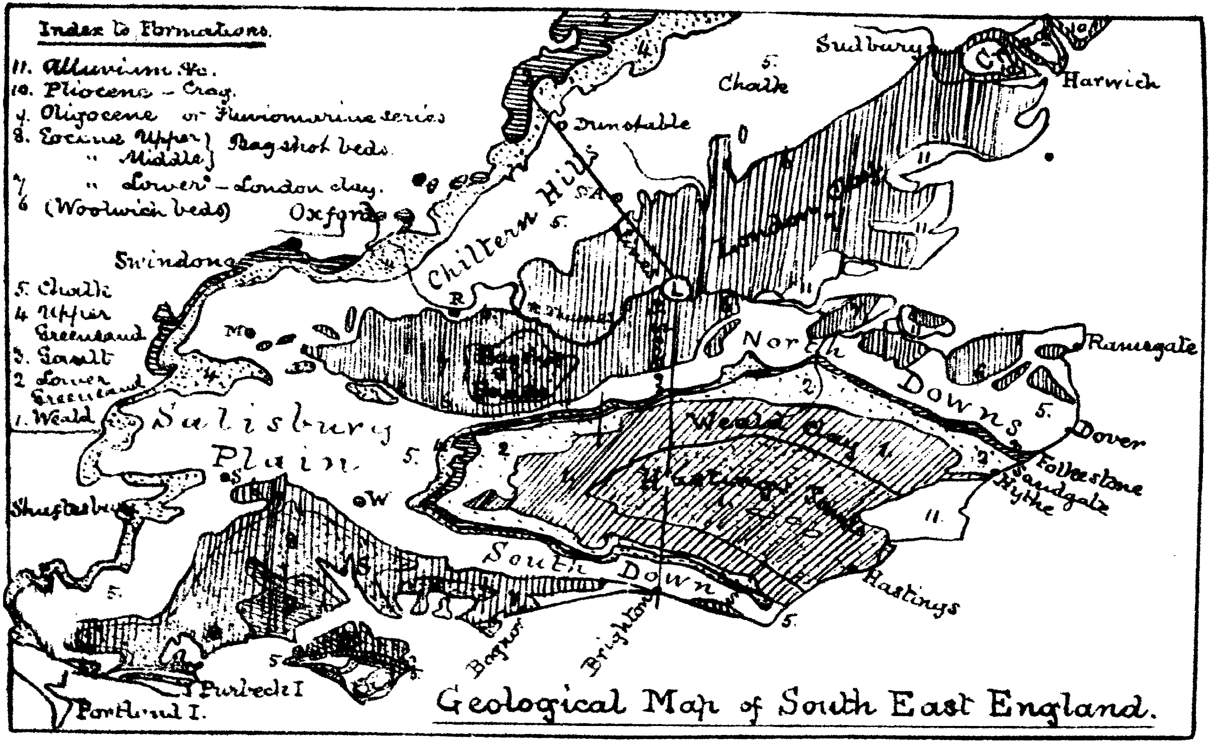


Diagram to show the relations to each other of Volcanic, Plutonic and Metamorphic rocks.

▨	Plutonic rocks, such as Granite, Syenite, Diorite, Gabbro; due to solidification of lava under pressure.
▤	Volcanic rocks of lava solidified at or near surface.
d.	Dykes or nearly vertical sheets of solidified lava.
i.	Intrusive sheets; and v. Veins of the lava.
c.	Interbedded or Contemporaneous sheets of lava, solidified in air, or under shallow water.
▩	Metamorphic or altered Stratified rocks, e.g. Schists, Gneiss, Quartzite, Slate, Marble.
U.	Unaltered stratified rocks, e.g. Clay, Sand, Shale.
S.	Sediments of sand, mud, &c, forming on the sea-bed, from denudation of the land.

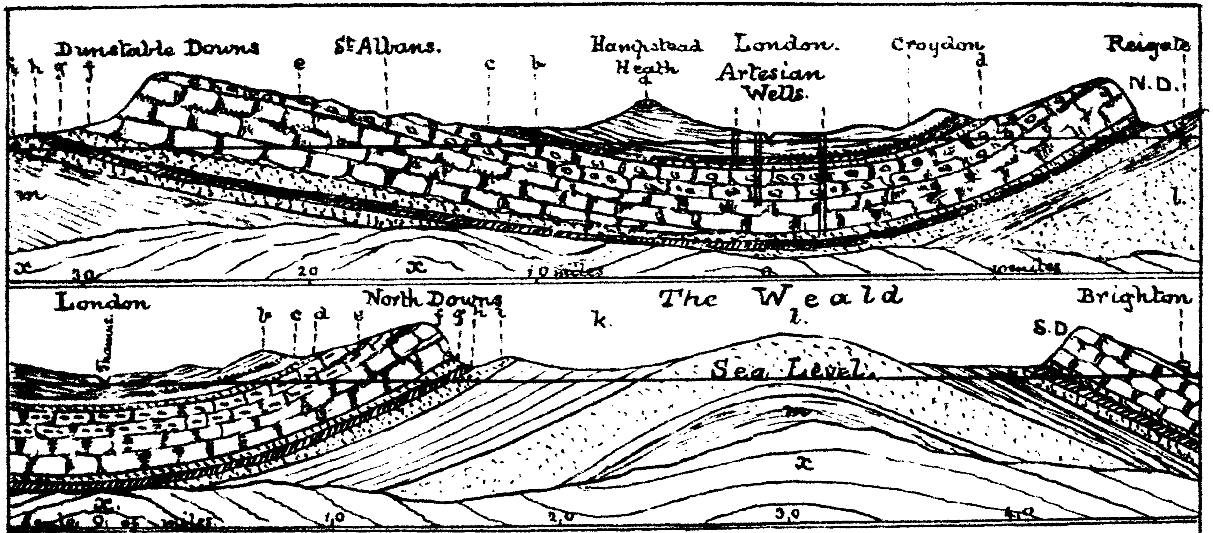
The metamorphism or alteration, due chiefly to the heat of the liquid rock, extends all around the Lava Lake, as also the Dykes, Veins, and Intrusive sheets; but of course affects only the beds beneath the Interbedded sheets.

V.



Geological Map of South East England.

VI.



Sections across I. The London Basin; and II. The Anticlinal of the Weald.

For the directions of the lines of section see Map.

a. Lower Bagshot.
b. London clay.
c. Woolwich beds.
d. Thanet sand.

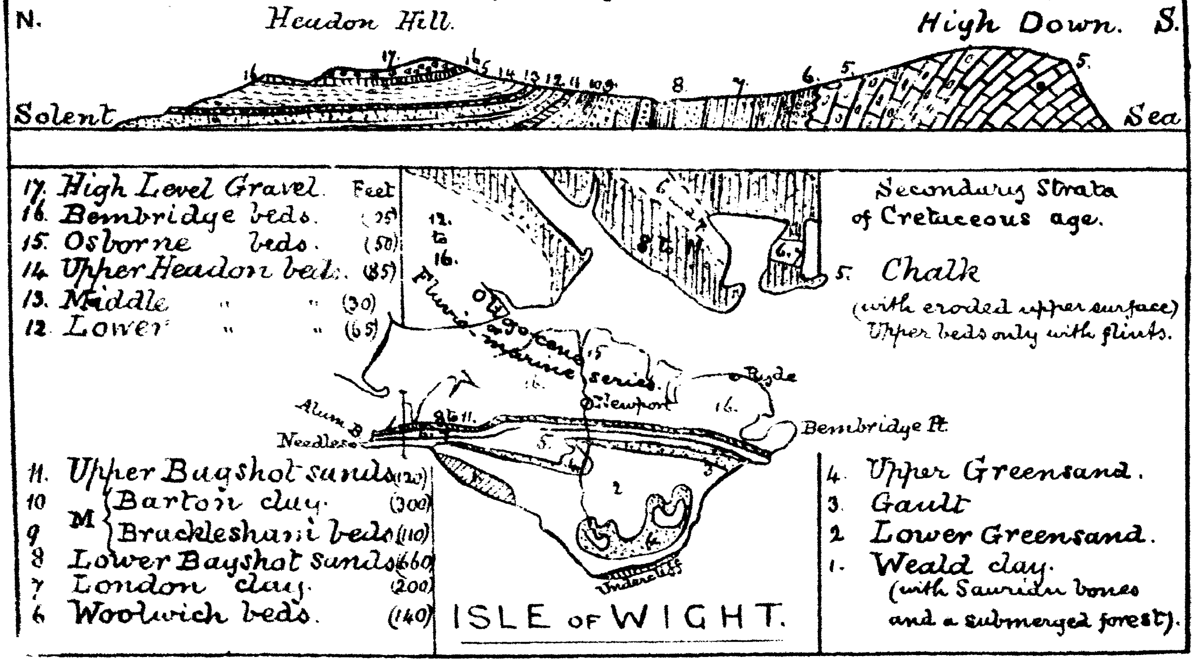
e. Chalk with flints.
f. Chalk without flints.
g. Upper Greensand
h. Gault.

i. Lower Greensand
k. Weald clay.
l. Hastings sand.
} Neocomian Beds.
m. Oolitic strata

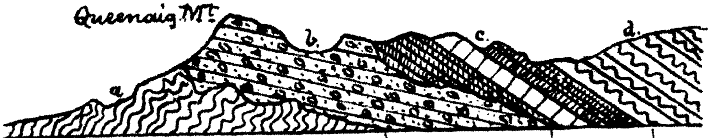
x. Old Rocks.

VII.

Section across the Isle of Wight (by H.W. Bristow F.R.S.)

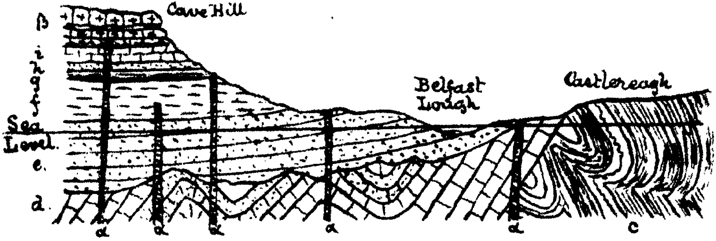


Section (diagrammatic) in North West Scotland.
after Murchison.



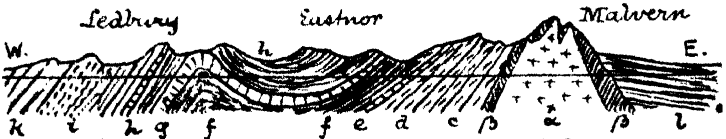
Gneiss with Granite veins of Pre-cambrian (? Laurentian) age. | Conglomerate ? Cambrian | Quartzite Silurian. | ?

The group d. are Schists, Gneiss, &c, and thought to be Pre-Cambrian



Section across Belfast Lough in N. E. Ireland.

α. Dykes of basalt &c. β. Basalt of the Antrim plateau.
c. Lower Silurian & d. Carboniferous series.
e. Red sandstones & f. Red marls of Triassic age.
g. Lias. h. Greensand. i. Chalk with eroded surface.
The basalt is of Miocene (or Oligocene) age.

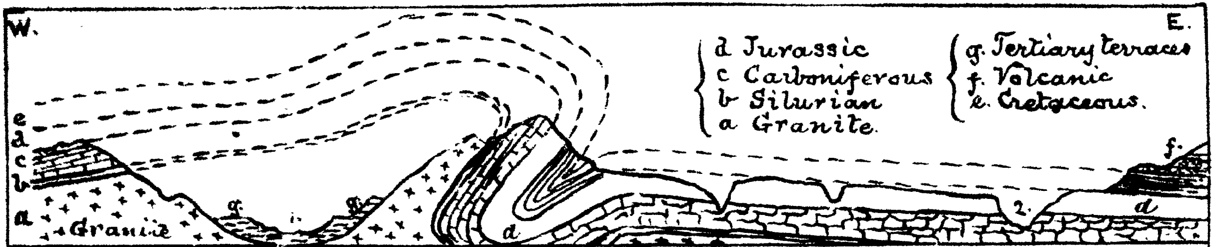


Section from Ledbury through the Malverns.
Distance about 5 miles. [From 'Siluria'.]

α. Eruptive rocks — Syenite, &c, — forming the axis of ridge. True granite occurs; and Felstone abounds.
β. Metamorphic rocks — Quartzite, Mica Schist, Gneiss.

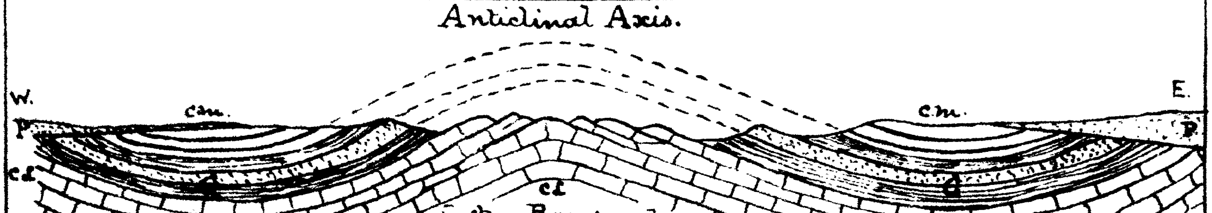
c. Lingula Flags (?) — Hollybush Sandstone, Schists, &c.
d. Upper Llandovery sandstone.
e. f. g. Lower & Upper Wenlock limestones and shale.
h. Lower Ludlow beds. i. Upper Ludlow beds.
k. Old Red Sandstone. l. New Red Sandstone.

IX.



Section to show Folding of Strata with Inversion. Montana U.S.A.

The area shown lies just North of the Yellowstone National Park. 1. Madison R. 2 Gallatin R.



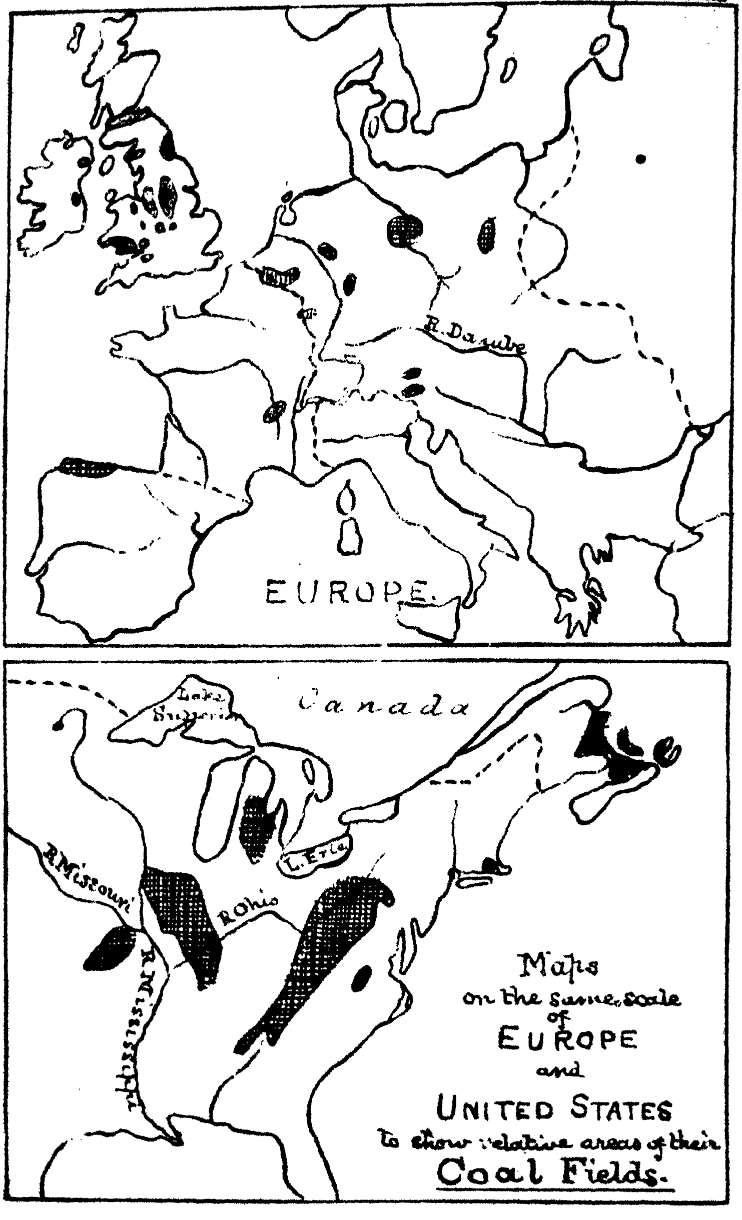
[after Ramsay.]

Diagram showing the Origin of the Basin-shaped form of many Coalfields.
[It nearly represents the Lancashire and Yorkshire Coalfields, once united.]

C.M. = Coal Measures.
G. = Millstone Grit & Yoredale rock
C.L. = Carboniferous Limestone.

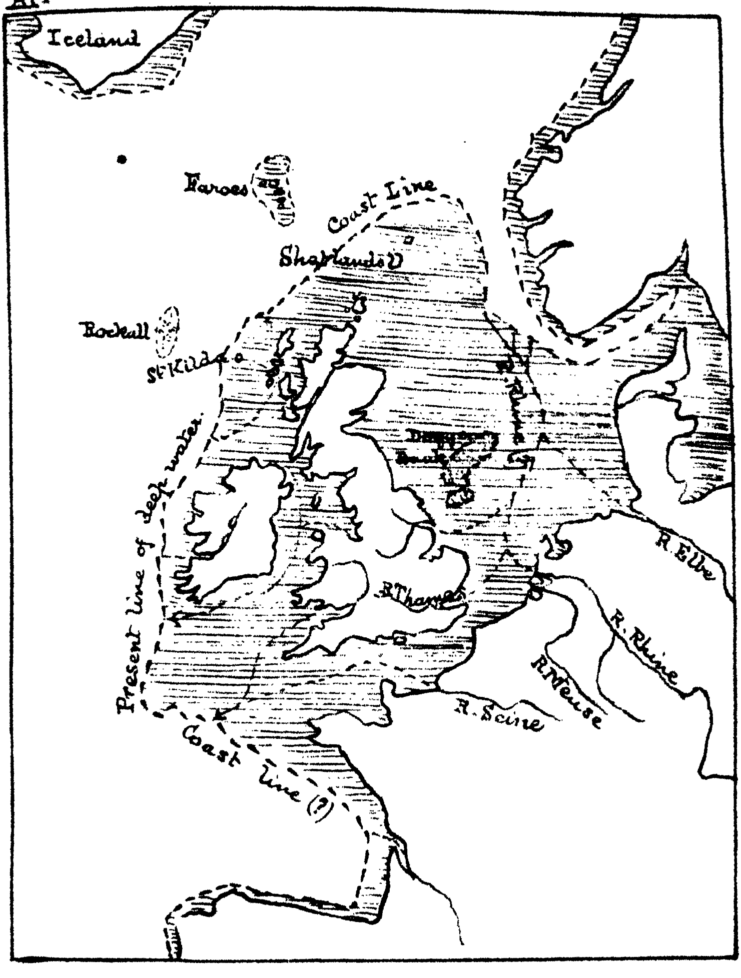
P. = Permian and newer rocks.
Note. To form true basins there must be folding of the strata in two directions.

X.



Maps on the same scale of EUROPE and UNITED STATES to show relative areas of their **Coal Fields.**

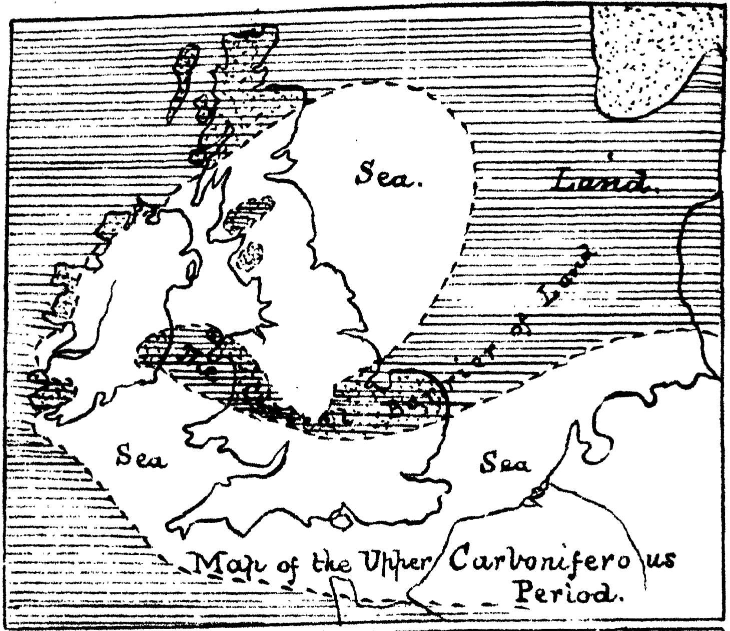
XI.



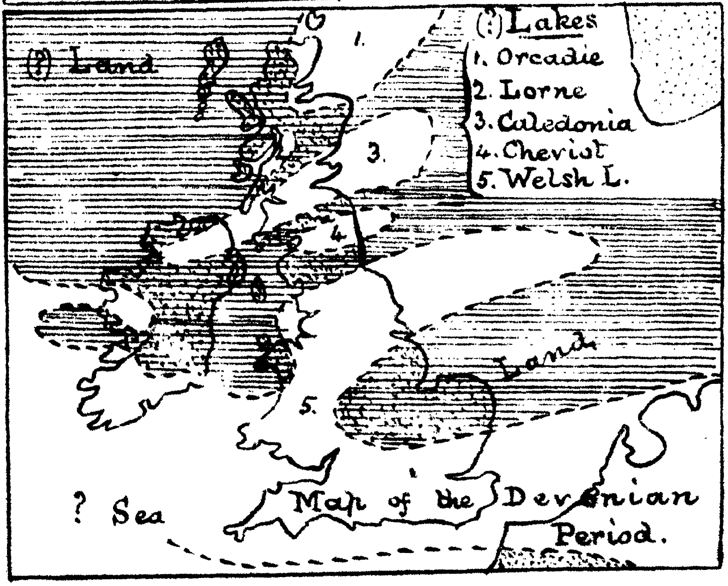
MAP OF NORTH WEST EUROPE

To show the part of the continent that is submersed.
The shaded parts are less than 600 feet below Sea level.
the outer dotted line being the 100 fathom line.
The inlet just South of Norway is half a mile deep.
The probable courses of the chief rivers are shown.

XII.



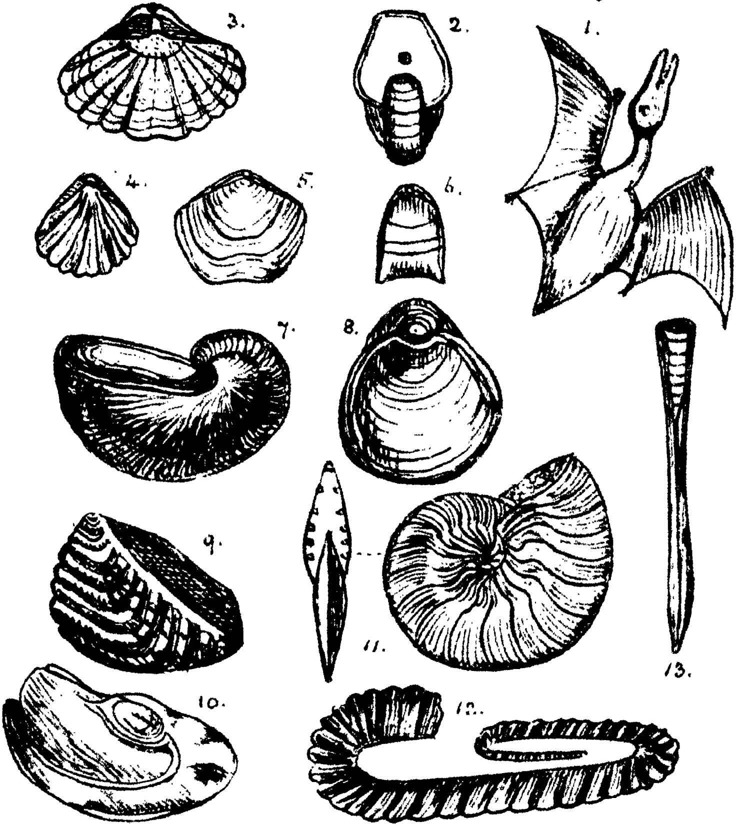
Map of the Upper Carboniferous Period.



Map of the Devonian Period.

XIII.

Some Mesozoic Forms of Life.



1. Pterodactyl — a flying Lizard (Supposed form) (Lias)
2. Nautilus truncatus. (Lias.
3. Spirifer Walcottii.
4. Rhynchonella rimosa.
5. Terebratula numismalis
6. Terebratula digona.

} Brachiopoda

7. Gryphaea incurva.
8. Gryphaea dilatata.
9. Trigonia Goldfussii.

} Conchifera.

(— Great Oolite.

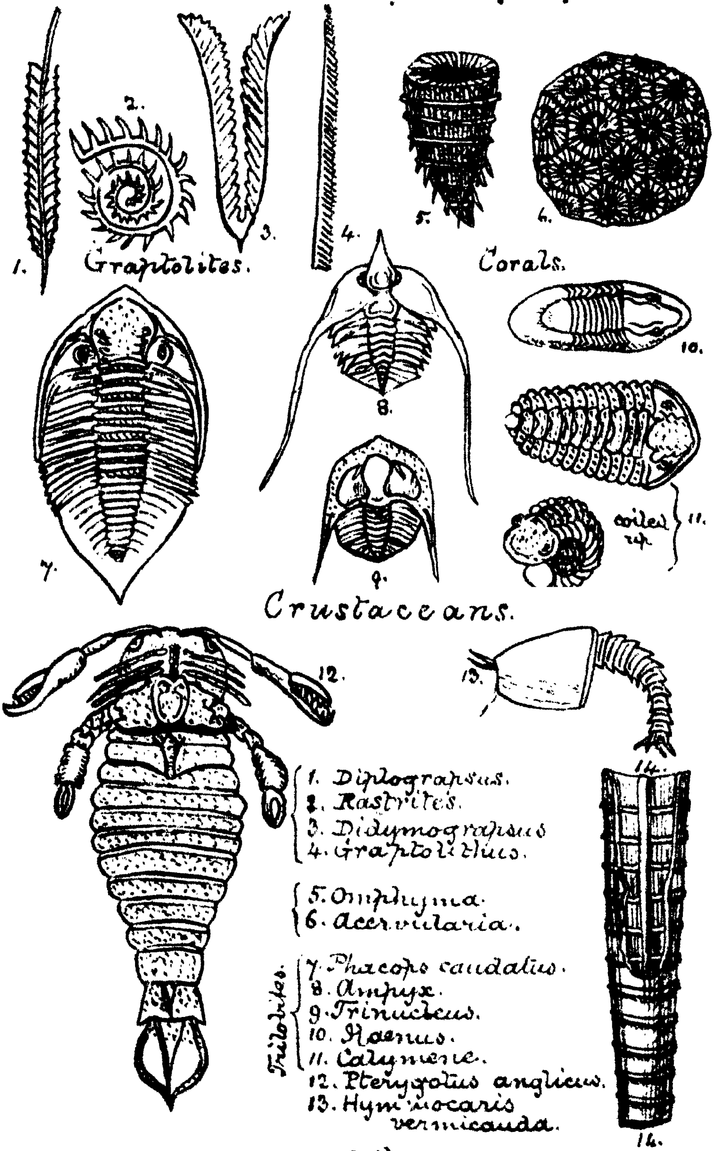
10. Trigonia incurva. (cast of interior) (— Portland Oolite.

11. Ammonites discus. (Cornbrash
12. Hamites attenuatus. (Gault.
13. Belemnites hastatus. (Oxford clay.

} Cephalopoda.

XIV.

Some Palaeozoic forms of Life.



1. Diplograpsus.
2. Rastrites.
3. Didymograpsus
4. Graptolithus.

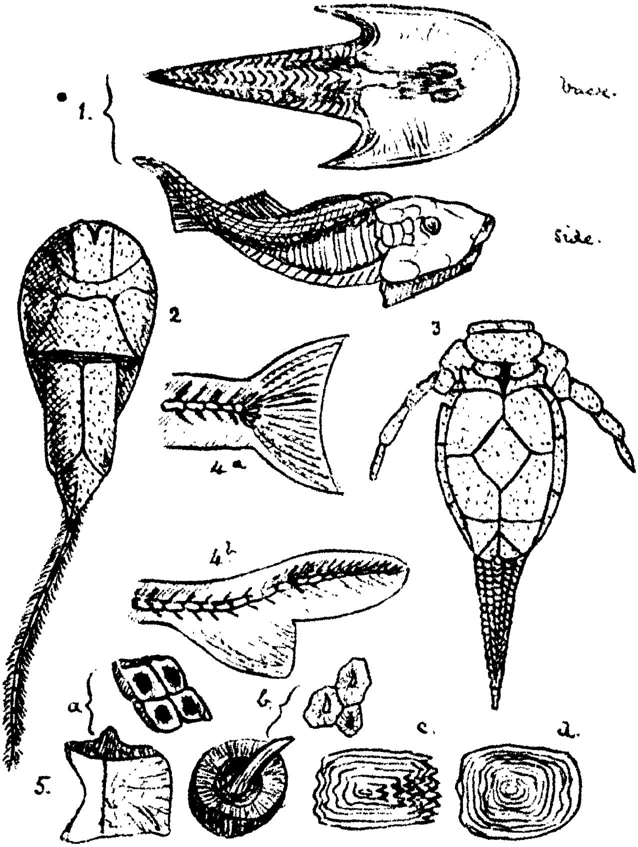
5. Omphyma.
6. Acervularia.

Trilobites.
7. Phacops caudatus.
8. Ampyx.
9. Trinucleus.
10. Illaenus.
11. Calymene.
12. Pterygotus anglicus.
13. Hymenocaris vermicauda.

14. Orthoceras mendax.

XV.

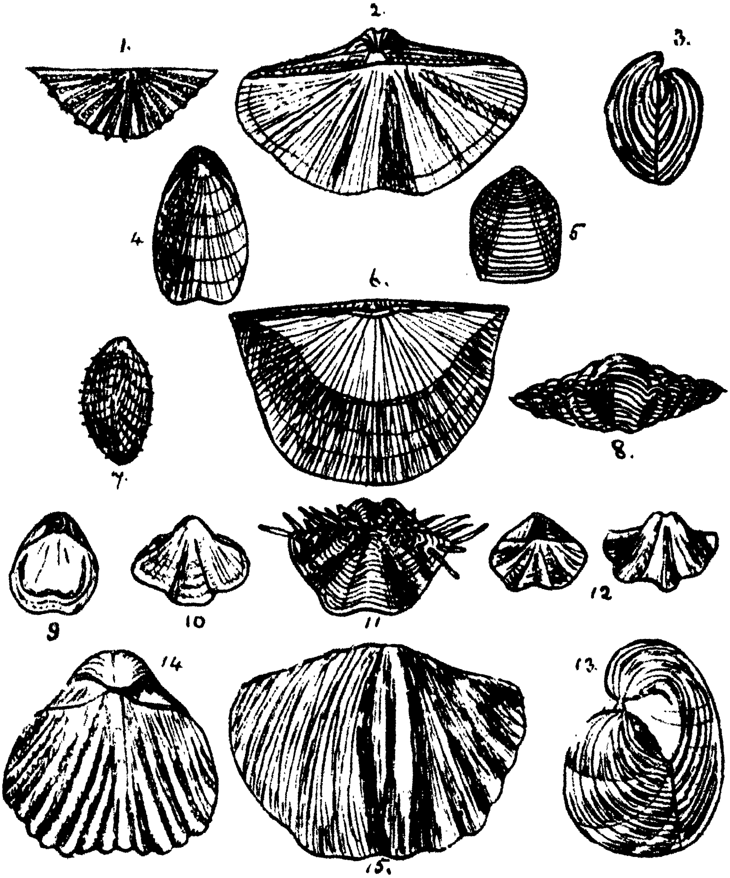
Fishes of Old Red Sandstone.



1. *Cephalaspis Lyelli* (the buckler-headed fish).
2. *Coccosteus decipiens*. 3. *Pterichthys Milleri*.

4a Homocercal tail. 4b Heterocercal tail.

5a Ganoid scales; bony plates covered with enamel.
b Placoid scales; enameled, often with a spine.
c. Ctenoid scales; no enamel jagged at edge.
d. Cycloid scale. -- entire at edge.



Brachiopod shells of Palaeozoic age.

1. Orthis alata. Lr Sil.
2. Spirifer striata. Carb. L.
3. S. plicatella (side). "
4 Terebratula hastata. "
5. Lingula Davisii. U. Camb.
6. Strophomena euglypha } Up. Sil.
7 Atrypa reticularis. }

8. Spirifer speciosa (edge). Dev.
9. Terebratula sufflata. }
10. Camarophoria }
11. Productus horridus. }
12 Spirifer alata (variety) } Permian
13. Pentamerus Knightii } Up. Sil.
14 " galeatus }

15. Productus giganteus. Carb. L.

SYLLABUS.

SUBJECT XII.—GEOLOGY.

FIRST STAGE OR ELEMENTARY COURSE.

A.—Preliminary Subjects.

a. BASIS OF GEOLOGY.—Definition of Geology. Its objects. Waste of land now brought about by mechanical causes,—wind, rain, running water, frost, snow, glaciers, and the sea. Origin of boulders, rounded pebbles, grains of sand, and mud. Detritus carried in mechanical suspension in rivers. The cementing substances that bind together incoherent rock-forming materials. Deposition of strata now going on in seas, estuaries, and lakes, from sediments formed mechanically. Other strata formed in part or entirely of organic remains. Proof that stratified rocks generally were formed by deposition from water, as above. That strata have been successively deposited and are of various ages. That strata of different ages are characterised by special fossils. The principal tests of the relative ages of stratified rocks. Definition of the term igneous or eruptive as applied to rocks.

b. COMMON GEOLOGICAL TERMS.—Definition of "Crust of the Earth," clay, shale, marl, marl-slate, sand, sandstone, conglomerate, breccia, limestone, lava, volcanic ashes; stratum or bed; a formation, group of formations. Recent, Cainozoic (Tertiary), Mesozoic (Secondary), and Palæozoic formations. Outcrop, dip, strike. Horizontal, inclined, vertical strata. Anticlinal and synclinal curves. Contorted and inverted strata. Basin. Conformable and unconformable stratification. Diagonal or cross-stratification. Overlap, joint. Fissile or flaggy structure, lamination, foliation, cleavage. Fault, lode, vein, dyke. Hade. Ripple-marks, rain-pittings, sun-cracks, and their indications.

c. COMPOSITION OF PRINCIPAL ROCKS AND THE COMMON ROCK-FORMING MINERALS.—Minerals that form Granites. Syenites, Diorites (Greenstones), Dolerites (Basalts), Volcanic Ashes (Tuffs), &c., Serpentine; Gneiss and mica-schist. Limestones, Dolomite, and Calcareous Tufa; Clays, Shales, Slates, Sandstones, Grits, Ironstone, Flint, Chert, &c.; Coal, what originally formed from. Colouring matter of rocks. Formation and mode of occurrence of nodules and nodular concretions. Characters of the more important igneous, aqueous, and metamorphic rocks.

d. DISINTEGRATION AND SOLUTION.—Disintegration and solution of minerals composing rocks; origin of soils. Springs mineral and springs thermal, and substances in chemical solution in rivers, lakes, and the sea.

e. SNOW AND ICE.—How glaciers are formed. Movement of glaciers and transport of matter on their surfaces. Moraines. Roches moutonnées. Perched blocks. Boulder-clay, and other glacial deposits. Erosion of rocks over which glaciers flow. Icebergs, whence derived. Transport of matter from cold to warmer latitudes by icebergs.

f. RIVERS.—Cutting out of valleys, and cañons, by rivers. Terraces Transport of material seaward, and formation of Deltas and bars.

g. MARINE DENUDATION, TRANSPORT AND CONSOLIDATION OF MATERIAL AND FOSSILIZATION.—Waste of sea-coasts by breakers and by help of landslips. Rounding of pebbles and grains of sand on shores by the action of wind, directly on land—indirectly in water, and in streams. Formation of Shingle-beaches and of Sand-dunes. The effect of long-continued marine denudation on land; formation of bays and head-lands, &c. Distribution of sediments derived from land over sea-bottoms, forming modern marine strata. Consolidation of strata by pressure, chemical changes, the introduction of cementing matter, and by heat. FOSSILS. Preservation of shells, &c. in (marine, lacustrine, and estuarine) deposits, in caverns, and in alluvium, and in and under peat, blown sand, shell-mounds, and volcanic ashes. Fossil casts. Modes of fossilization.

h. INTERNAL HEAT, VOLCANOS, EARTHQUAKES AND OTHER MOVEMENTS OF THE EARTH'S CRUST.—Evidence of the gradual sinking and rising of the sea-bottom. Coral Reefs:—Fringing-reefs, barrier-reefs, atolls. Volcanos and their connexion with some areas of upheaval of land above the sea. Raised Beaches. The structure of Volcanos. Earthquakes. General structure of mountain chains. The evidence of the existence of so-called central heat in the earth. Probable thickness of the Earth's crust. Change of sedimentary strata—such as shale and slate, sandstone, limestone, &c., into mica-schist, gneiss, quartzite, crystalline limestone, &c. (metamorphism).

B.—Classification of Animal and Vegetable Life.

i. A rudimentary acquaintance with the meaning of the names of the CLASSES and ORDERS of the animal and vegetable kingdoms; more especially of those forms of life which are found as fossils.

C.—Palæozoic Series.

Succession of Strata, Igneous Rocks, &c. (as developed in Britain), noting the more important economic products:—Coal, ironstone, and ores of other metals, salt, building-stone, slates, &c.

k. Oldest known strata or the Archæan or Pre-Cambrian rocks. Their metamorphic character. Oldest known fossil.

l. CAMBRIAN AND SILURIAN.—Their main sub-divisions, and their more characteristic groups of fossils:—Graptolites, Trilobites; relative abundance of Brachiopoda. First appearance of fish, and of land-plants.

m. OLD RED SANDSTONE AND DEVONIAN.—Differences between them, and the areas in which each occurs. Supposed fresh-water character of the Old Red Sandstone; its characteristic fossils.

n. CARBONIFEROUS.—The ordinary succession of these strata in Wales and the South-west of England. The corals, shells, and fish-remains found in the Carboniferous Limestone, and other beds. The succession of strata sections found in the Coal-measures. The Underclay generally below beds of coal. Formation of coal. How there came to be many beds of coal in one coalfield with beds of shale, ironstone, and sandstone between.

o. PERMIAN.—Order of succession in England, and the proofs of unconformity on the Carboniferous strata. The chief fossils of the

D.—Mesozoic or Secondary Series.

p. NEW RED SANDSTONE OR TRIAS.—British divisions: 1st. New Red Sandstone (Bunter); 2nd. New Red Marl (Keuper). Unconformity on Permian and older rocks. Great changes of life in passing from Palæozoic to Mesozoic times. Origin of Rock Salt by evaporation of salt water. Gypsum of Red Marl.

q. PENARTH OR RHÆTIC BEDS.—

r. LIAS AND OOLITES.—(Jurassic.) The names of the chief formations. General characters of the rocks. Great development of life of these periods. Leading marine fossils of the Lias, and land-plants and Insects. Common genera of Brachiopoda and Conchifera, Gasteropoda, Cephalopoda, Echinodermata, Fish, and Reptiles. Leading fossils of the Oolites as above, and also Mammalia. Proofs of land in the neighbourhood of the British Liassic, and Oolitic seas.

s. PURBECK AND WEALDEN.—Their estuarine and freshwater characters, and proofs of these from the fossils. Generic names of leading fossils. Proofs of the existence of a neighbouring large continent.

t. CRETACEOUS SERIES.—British divisions, Lower and Upper, and their subdivisions. The nature of the strata and general grouping of fossils (as in *r* above). Differences when compared with Oolitic genera and species.

E.—Cainozoic or Tertiary Series.

u. EOCENE OR LOWER TERTIARY.—Meaning of the terms Eocene, Oligocene, Miocene, and Pliocene. Areas occupied by the English Eocene strata, and their divisions. Their fossils—freshwater, estuarine, and marine. Fluvio-marine series of the Upper Eocene (or Oligocene) of the Hampshire Basin. Plant beds of Bovey-Tracey, Bournemouth, Alum Bay, Mull, &c. (some of these formerly classed as Miocene). Remains of insects, mammals, reptiles, molluscs, &c.

v. PLIOCENE, CRAG, &c.—Divisions of the British Crag, characters, and fossils, marine and terrestrial. Economic products. Proportions of recent species in the different members of the Crag. The Forest Bed beneath the Boulder Clay, and its Flora, terrestrial Fauna, and shells.

w. GLACIAL EPOCH, AND STRATA LATER THAN THE CRAG.—The glaciers of the Glacial Period. The origin and nature of the Boulder Clays. Other proofs of a cold climate, and the marine and terrestrial Fauna of the period.

x. POST-PLIOCENE, POST-TERTIARY, AND RECENT.—Alluvium, Peat, and other deposits now forming. Raised Beaches. Submerged or Submarine Forests. River Terraces, Bone Caves and their contents, &c.

SECOND STAGE OR ADVANCED COURSE.

A.—Preliminary Subjects or Principles.

1. All contained in *a* of the elementary stage.
2. All contained in *b*.
3. All contained in *c*. The chemical composition and crystallographic forms of the different species of rock-forming minerals included in the Felspar group, the Amphibole group, the Pyroxene group, and the Mica group. Garnet, Tourmaline (Schorl), Apatite, Epidote, Chlorite.

Pyrites, Titaniferous and Magnetic iron, Quartz and other varieties of silica; Calcite, Zeolites, &c. The different varieties of Coal. Mode of occurrence of the principal ores. Principal varieties of rocks, sedimentary, eruptive, and metamorphic. Their mode of occurrence, mineral composition, and microscopic structure. Their industrial applications. Nature of metamorphism.

4. CHEMICAL DISINTEGRATION.—Chemical disintegration of rocks on a large scale; action of water charged with carbonic acid upon limestones. Weathering of granite rocks, and formation of kaolin. Origin of mineral and thermal springs, and of the substances in solution in them and in rivers, seas, and other waters. Cementation of incoherent rock-forming matter. Remains of testacea and other marine and fresh-water animals, whence derived, and how strata are formed of these.

5. EFFECTS OF SNOW AND ICE.—Glaciers, and how they are formed. Change of snow into solid ice. Stratification and veined structure of ice. Inclinations of beds and surfaces of glaciers. Why glaciers flow. Rates of progress. Crevasses. Moraines—lateral, medial, terminal, and how they are formed. Work done by glaciers. Erosion of rocks under glaciers and its results. Flow of water from lower ends of glaciers. Destruction of terminal moraines, and circumstances that induce their occasional preservation. Oscillation of size of glaciers. Deepening of valleys. Signs left by glaciers that have disappeared. Icebergs of Arctic and Antarctic regions and of South America; how formed. Ocean currents. Transport of matter by icebergs, and its distribution over existing sea-bottoms. Transport of detritus by coast-ice and river-ice.

SUBAERIAL, AERIAL, AND ÆOLIAN ROCKS.

6. RAIN, SPRINGS, AND LANDSLIPS.—Action of wind and running water. Landslips in mountainous and hilly regions, and landslips on sea-coasts. Their effect in bringing matter within the influence of running water and of the sea.

7. RIVERS.—Erosive and transporting power of brooks and rivers. Their influence in forming gorges and valleys. Origin of waterfalls. Amount of matter carried seaward by great rivers such as the Nile, the Ganges, the Mississippi, &c. The mode of formation and gradual growth of Deltas and their possible age. Filling up of lakes by sediments. General effects on the form of the ground and lowering of level of continental and smaller areas by combined effects of chemical disintegration, and mechanical disintegration by rain, rivers, frost, snow, and glacier-ice.

8. MARINE DENUDATION.—Waste of sea-coasts by breakers and landslips. Formation of pebbles and sand on sea-coasts. Power of breakers in moving sand and shingle, and large blocks of stone. Effect of prevalent winds on waste and transport of material along shores. Silting up of estuaries. Effect of groynes and other artificial obstructions on coasts. Warping of alluvial tidal flats. Forms of sea cliffs, and origin of many bays and headlands. Comparison of sea-cliffs with escarpments. Origin of great plains of marine denudation by combined action of breakers and landslips; and general lowering by waste of the interior of countries. Subsequent upheaval of such plains and renewed scooping out of valleys. Origin of certain table-lands and their valleys. Origin of cañons.

9. DISTRIBUTION OF MATERIAL IN SEA, &C. FORMING MODERN STRATA.—Transport of matter by great marine currents, passing mouths

of rivers and along coasts. Transporting powers of tidal currents. Sorting action of the sea in arranging sediments along its bottom. Icebergs (see 5). Modern formation by above causes of beds of clay, sand, gravel, and boulder beds, and mixtures of these. Deep-sea deposits of modern seas; and wide distribution of deep-sea forms of life with localization of littoral forms; importance of this distinction in Geology. Volcanic Ashes falling in sea and lakes. General formation of lacustrine strata. Formation of beds of limestone by organic bodies in seas, lakes, and lagoons. Coral Reefs (see 11). Salts carried in solution by rivers into lakes; evaporation of such solutions, concentration and precipitation. Origin of Rock Salt, &c.

10. FOSSILIZATION AND CONSOLIDATION OF STRATA.—Shells and other marine organic remains buried in sediments. Also Terrestrial Plants. Worm-burrows. Terrestrial animals. Organic remains in lakes and river-deltas, in alluvial beds and brickearths; in and under peat, under blown sand, and in volcanic ashes and under lavas. Formation of sediments by foraminifera, &c. in deep seas. Modes of distinguishing rocks formed in estuaries, deltas, and seas. Consolidation of strata by pressure, infiltrations, and precipitations, chemical decomposition and recomposition, and by heat.

11. SUBTERRANEAN HEAT, VOLCANOS, EARTHQUAKES AND OTHER MOVEMENTS OF THE EARTH'S CRUST.—Theory of Coral Reefs. Fringing Reefs, Barrier Reefs, Atolls, and proofs of gradual subsidence of the sea bottom. Recent views on this subject. Connexion of coral reefs with the volcanic islands of the Pacific Ocean and areas of partial upheaval. Upheaval of the west coast of South America. Oscillations of level on the coast of the Baltic, Greenland, &c. Raised beaches.

Theories of central heat how inferred. Radiation of heat from the Earth, consolidation, and theory of the formation and shrinkage of its crust. Thickness of the Earth's crust. External phenomena of Volcanos, and theories of volcanic action. Ages of the various volcanic rocks in the British Islands. Earthquakes. Oscillations of level accompanying earthquakes.

Metamorphism of rocks. Influence of heated water in producing metamorphism. Theory of slaty cleavage; passage of shales, clayslate, sandstone, limestone, and their intermediate gradations into mica-schist, chlorite-schist, various kinds of gneissic rocks, granulite, quartzite, crystalline limestones, &c. Special development of distinct minerals in rock-masses. Relation of the above to gradual subsidence of rock-masses and accumulation of strata above them. Metamorphism of Igneous Rocks, and the supposed conversion of such rocks into schists, gneiss, &c., by heat, pressure, earth-movements, &c. Origin of mountain chains. Disturbance and contortion of strata in successive stages, and probable causes of these phenomena. Relative ages of mountain chains.

B.—Classification of Animal and Vegetable Life.

12. All contained in *i* of the Elementary stage, together with a general knowledge of the orders of Mammals, Birds, Reptiles, Amphibians, Fish, Insects, &c., Crustacea, Echinodermata, Cephalopoda, Pteropoda, Gasteropoda, Conchifera, Brachiopoda, Polyzoa, Cœlenterata, Protozoa, &c., and the classes and orders of the Vegetable Kingdom. Relative importance of these groups in correlating strata.

Succession of Strata, Igneous Rocks, &c.

In all cases attention should be paid to the proofs of contemporaneous volcanic action; to the physical geography of the areas occupied by the various formations; and to the chief economic products which they yield.

C.—Palæozoic Series.

13. The Archæan and Metamorphic rocks of the British Isles, and of the Continents of Europe and America. Theories as to their origin and relative ages.

14. Cambrian and Silurian.—Different views as to the classification of these strata, their main subdivisions and characteristic fossils; unconformities in the series, and the relation of these unconformities to breaks in succession of life.

15. Old Red Sandstone and Devonian.—Passage of Upper Silurian into Lower Old Red Sandstone in Wales and on its borders. Disappearance of the life of the Silurian period. The land that existed in Scandinavia and Britain before the deposition of the Old Red Sandstone, and around and on which the Old Red beds were deposited. Fish of the lower Old Red Sandstone; their distinctive characters.

Upper Old Red Sandstone.—Lithological characters, fish, shells, and plants. Cornstones. Unconformity of the Upper on the Lower Old Red Sandstone, and approximate or actual passage of the former into the Lower Carboniferous strata. Condition of the waters in which the Old Red Sandstone formations were probably deposited. If partly glacial, and the signs of this?

Devonian.—The division of these strata commonly made into Lower, Middle, and Upper Devonian. The marked difference of conditions of deposit shown in the general nature of their fossils, viz., the Fish of the Old Red Sandstone, and the Corals, marine bivalve and univalve shells, Cephalopoda and Trilobites of the Devonian strata. The stratigraphical relation of the Devonian strata to the Silurian rocks of Devon and Cornwall. The relation of the so-called Upper Devonian beds to the Carboniferous strata. The appearance of new genera and species in the Devonian rocks.

16. Carboniferous.—Succession of Carboniferous strata in South Wales, and its borders, and in the south-west of England, viz., Lower Limestone Shale, Carboniferous Limestone, Upper Limestone Shale, Millstone Grit, and Coal Measures. The lithological characters of these and their fossils—marine, freshwater, and terrestrial. The manner in which the beds below the Coal Measures were accumulated. The manner of the formation of the Coal Measures, the peculiar strata beneath each bed (or most beds) of Coal, the nature of the plants that formed the coal, their mode of growth, and the cause of the succession of beds of coal in thick series of strata. The gradual change of the above-mentioned Carboniferous strata into a set of beds differently arranged in their stratification, especially in their lower members, proceeding northwards through Lancashire and Yorkshire into Northumberland, and Scotland. The physical causes that produced this difference. The Carboniferous series as developed in Ireland. The Carboniferous rocks of the continents of Europe and North America. Their resemblances to those of the British Islands. Climate, its average uniformity in space and time during this epoch. The surface areas occupied by the European Carboniferous strata now. The areas where they may be concealed under newer formations. The areas where they were originally formed, *i.e.*, which they spread over before being reduced to their present limits by denudation. The disturbances of the Carboniferous rocks), and the reasons why coal-fields (like parts of many other formations so often

lie in basin-shaped areas. Various kinds of coal, such as the varieties of coal commonly called bituminous, cannel, and anthracite. The chemical changes that vegetation underwent in its conversion into coal, first on the surface, and afterwards under pressure. The passage of bituminous coal into anthracite: the probable reason, and the connexion of this subject with highly disturbed areas. Development of Crustacea of the Carboniferous rocks as distinguished from those of the Devonian and Silurian periods. Prevalence of certain genera of Brachiopoda and Conchifera, and relative proportions of these in the Carboniferous rocks when compared with older formations. Fish and Reptiles of the Carboniferous rocks. Footprints, Rain-drops, Land-shells, and Insects, and what they indicate. Ironstones. Mineral veins in Carboniferous Limestone series. Coal, hæmatite and lead-ore in the North of England.

17. PERMIAN.—Succession in Britain, Germany, and Russia. 1. The Rothliegende, its structure, and the evidences of the glacial agencies by which parts of it were deposited. 2. The Kupferschiefer of Germany and Marl-slate of England, with mineral contents, fish, &c. 3. The Magnesian Limestone (Zechstein), its mineral character and composition; its fossils; evidence of their Palæozoic character, partial community of species, and numbers and size when compared with the genera and species of the Carboniferous Limestone. Cause of this. Unconformity on the Carboniferous and older rocks; submersion of old lands during its deposition; bearing of this on conglomeratic and brecciated structure of the Rothliegende and the general development of the life of the period, including plants and reptiles. Relations of the Permian to the Carboniferous, and to the Trias in Britain and on the Continent.

D.—Mesozoic or Secondary Series.

Lower Mesozoic.

18. DIVISIONS OF TRIAS, OR NEW RED SANDSTONE SERIES.—Break in succession of life in passing from Permian to New Red Sandstone. Great development of Conchifera, and decrease of genera of Brachiopoda. The relation of this to lapse of time, as shown by unconformity, and continued prevalence in later times of many of these early Mesozoic types. The generally unfossiliferous character of the New Red Sandstone beds (Bunter) and their minor divisions in England. The absence in England of the Muschelkalk. Its fossils. The minor divisions of the New Red Marl (Keuper). Its fossil plants and reptile-bones and footprints. Microlestes. Rain-pittings, Ripple-marks, and Sun-cracks. The rock-salt, gypsum, &c. of this formation, and how they were deposited. Theory of inland salt-lakes or seas of the present day, and the bearing of this and of the above-named marks of rain-drops and footprints on the point. Those parts of the British Islands that formed land before and during the New Red Sandstone period.

19. PENARTH OR RHÆTIC BEDS.—Intermediate between New Red Marl and Lower Lias. Gradual passage of nearly unfossiliferous red marls into these more fossiliferous strata. Character and names of some of the common fossils. Their affinities with Liassic forms, and the conformable passage into that formation in Britain.

20. LIAS AND OOLITES (Jurassic).—Names of the several formations of the Lias and Oolites between the Lower Lias and the Purbeck Beds in serial order. Lithological characters of the Liassic divisions. Fossils of the different formations. The distinctive characters of some of these, their relative numbers compared with the same classes in the Palæozoic rocks. Nature of the connexion of the Lias with the Inferior Oolite.

Lithological characters of the Oolitic formations and the uses to which the rocks of the different divisions are applied. Marine fossils of the different sub-divisions of the above-named formations; also Mammalia. Change in character of the Oolitic rocks when traced northwards through England; causes of this change. Evidences of the existence of older land in the neighbourhood of the Liassic and Oolitic seas, and of the climate of the period as inferred from the remains of plants and animals. Names of the most characteristic genera of the fossils of the Lias and Oolites, especially with reference to their prevalence: some notably characteristic species and the names of some of them. Jurassic strata of the continent of Europe; the Jura and the Alps; the fossils of Solenhofen. Disturbance and metamorphism of Jurassic strata. Contrast the life of these epochs with similar developments in Palæozoic epochs.

21. Purbeck and Wealden.—Their general fresh-water nature and marine interstratifications. Extent of these formations in England and on the Continent. Their characters and thickness. Fossils of the Purbeck strata. Plants, land-insects, mammals, fish, reptiles, univalve and bivalve shells, and crustaceans. Fossils of the Wealden formations as above. Evidences of the upheaval of extensive tracts of land during the period, and the manner in which the Purbeck and Wealden beds were deposited. Relation of the Purbeck to the Oolites, and of the Wealden to the Cretaceous.

Upper Mesozoic.

22. Cretaceous series.—Description of the British divisions and sub-divisions. Their lithological characters; and passage of Weald Clay into Lower Cretaceous beds in the Wealden area and in the Isle of Wight. Fossils of the formations noticed in the same way as those of the Oolitic strata. Neocomian beds of the Continent and their equivalents in Britain. Lower and Middle Neocomian of Yorkshire, &c.—the marine equivalents of the Wealden Beds. Upper Neocomian (Lower Greensand) of South-east of England. Gault and Upper Greensand. Chloritic Marl. The Chalk, by what organic bodies chiefly formed. Comparison with similar deposits forming in existing oceans. Nature and mode of occurrence of flints in chalk, and vein, and tabular flints. Resemblances and differences of the genera and species of the Oolitic and Cretaceous epochs, and the bearings these have on lapse of time between the deposition of the Portland Oolite and the commencement of the marine Cretaceous series. Continental Cretaceous geology generally. Hippurite Limestone. Highest Cretaceous rocks unknown in Britain. Maestricht beds and Chalk of Faxoe, Denmark. Upper Cretaceous beds and flora of Aix-la-Chapelle. Account of them. Cretaceous strata of America, and passage of these into Tertiary beds.

E.—Cainozoic or Tertiary.

23. Eocene or Lower Tertiary.—Meaning of the terms Eocene, Oligocene, Miocene, and Pliocene. Grouping of greater divisions and subdivisions of the English and French strata as usually given in text-books. Areas occupied by the English and French Eocene strata. Evidence of the upheaval of the Chalk and older strata of Western Europe before the Eocene period. The evidence shown by fossils of the manner in which the different formations or parts of formations were deposited; 1st, into three broad divisions, estuarine and fluvio-marine below; 2nd, marine in the middle; and 3rd, fresh-water, estuarine and fluvio-marine above. Correlation of this highest series with the Oligocene beds of the Continent. Evidences of land and its nature from plants and from mammalian remains. The nummulitic England, the Continent of Europe, Asia, and Africa.

of climates of Eocene times, as indicated by shells, reptiles, and plants, &c. Original extension and subsequent denudation of Eocene beds in Britain.

Plant-Beds of our British Tertiary Series; associated Igneous rocks of Antrim, Mull, &c. Some of these formerly referred to the Miocene. Reasons for and against this view.

24. MIOCENE OR MIDDLE TERTIARY STRATA.—Nature of the strata and their fossils. French marine and freshwater strata and igneous rocks. The fossils of the former and the Mammalia of the period. Miocene beds of the Rhine, Switzerland, Bohemia, and other parts of the continent of Europe and of the Arctic Regions. Their divisions, lithological characters, and fossils. Brown-coal of Germany, &c.; reference of some of the lower beds to the Oligocene. Disturbances of the Alps and Jura before and after the close of the Miocene epoch. Miocene rocks of India and their fossils.

25. PLIOCENE STRATA, CRAG, &c.—(See *e*.) and in addition proofs of Britain having been joined to the Continent before the Crag epoch. Crag of Belgium. Pliocene beds of Italy.

26. POST-PLIOCENE OR POST-TERTIARY, GLACIAL EPOCH, AND STRATA LATER THAN THE CRAG.—Old land-surface of Britain later than the Crag.—Forest beds, their plants, mammalia, and shells. The Glacial period. Great glaciers before the deposition of the Boulder Drift in the northern and southern hemispheres generally, and in Switzerland and other mountain ranges specially. The signs of this. Boulder beds and Arctic shells. Minor glaciers during and after the deposition of the boulder beds. Their signs. Erosion of valleys by ancient glaciers. Theory of the formation of rock-bound basins by glaciers and of other lakes by boulder beds and eskers or kaims. General nature of the fauna of the period. Union of the British Islands and their union with the continent before and after the Glacial Epoch. Theories of the causes that produce this glacial period and of glacial periods in general. Loess of the Rhine and other rivers, brick-earths, river-gravels, and alluvia of various ages. Mammalian and other bones in these in Europe, Asia, and America. Bone Caves and the manner of the preservation of their fossil contents. Relics of man and his works in caves, river-deposits, shell-mounds of Denmark, &c., and in Swiss and other lakes. Contours of ground before and after the Glacial Period. Origin of River-valleys. Pre-glacial and post-glacial valleys. River Terraces. Raised Beaches, &c.

27. Theories that have been proposed to explain the distribution of life in individual formations and throughout the whole geological series; or the origin, increase, distribution, and disappearance of species and genera commonly so called. The relations of the life of successive formations to each other generally. Relations of existing faunas and floras of the world to those of Miocene, Pliocene, and Post-pliocene age.

28. Water-bearing strata and underground drainage. Perennial, intermittent, and thermal springs. Artesian and other wells. Soils and their relations to the underlying beds or to drift deposits. Origin of mineral veins and lodes. Rocks in which ores are found, and mode of occurrence of ores in beds, lodes, and superficial detritus. The rules that ought to guide the miner in sinking for coal and other minerals, when the beds in which they lie are concealed by overlying and unconformable strata.

EXAMINATION FOR HONOURS.

In addition to the foregoing, candidates for Honours may be expected to be acquainted with any subject treated of in first-class standard manuals, with questions bearing on the history of Geology on the

present state of geological opinion on such subjects as Vulcanicity, the probable condition of the Earth's interior, and the action of ice as a geological agent; on the nature and effects of metamorphism; and on microscopic petrography.

The Examination will consist of a preliminary written paper, and those who qualify therein may be required to attend a practical examination at South Kensington at a subsequent date.